LOCAL MICROWAVE HEATING

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Experimental studies of the possibilities of practical implementation of local microwave heating technology have been carried out. The correspondence of the existing theoretical models of the process to what is happening in practice is shown. The results of measuring the temperature distribution over the sample when exposed to a radiating microwave coaxial probe are given. The directions for further improvement of the operating modes and the main components of the microwave modifier are determined.

Introduction.

The use of microwave energy of the electromagnetic field for heating different media is widely known and well-studied. As a rule, the developers of various directions of practical use of this method were faced with the task of ensuring a spatially uniform microwave heating. The task of localization arose very rarely, for example, during hyperthermia of tumors, and had a macro-dimensional nature. At the same time, micro-dimensional heating can be relevant in the interests of modifying micro-objects, and especially for micro- and nanoelectronics.

The development of high-local microwave heating allows doping and re-doping, thermal oxidation, recrystallization and annealing of various materials in the surface layer of the object, including those ones in film structures.

However, to achieve micron and submicron localization of microwave heating, it is necessary to solve the problem of optimal heat dissipation. For this, it is necessary to have an appropriate theoretical description of the method adapted to the type of the microwave transmitter used, for example, with a coaxial aperture.

The practical possibility of microlocalization of microwave heating appeared as a result of the development of near-field sources of microwave radiation, in particular, for scanning microwave microscopy [1].

The main part.

Theoretical studies of the localization characteristics of microwave heating of semiconductor and dielectric objects are based on the joint solution of electrodynamic and thermal problems for near-field sources of microwave radiation. The theoretical foundations of local microwave heating modeling are described in detail in [2, 3].

Fig. 1 schematically shows the possible functional scheme for the implementation of local microwave heating, as well as the type of electrodynamic structure of the micromodifier.

In modeling, a radiator based on a conical coaxial probe with a spherical and flat tip shape was considered as a local micromodifier. The radius of the tip is ~ 10 microns. The object of study is the "film on the substrate" structure.

As a result of model studies in [23-26], the following was established:

- temperature distribution inside and along the sample surface substantially depends on the size of the gap between the micromodifier point and the sample surface;

- the spatial distribution of temperature in the sample, depending on the shape of the point of the tip (flat or spherical) also changes - for a spherical one, it is of more localized nature;

- local heating of the sample leads to a local change in the electrical characteristics, which additionally accelerates the heating process;

- during long-term (more than 10^{-3} s) exposure of the microwave radiation to the sample, heat spreads over the sample due to its thermal conductivity, which leads to a decrease in the degree of localization of heating.

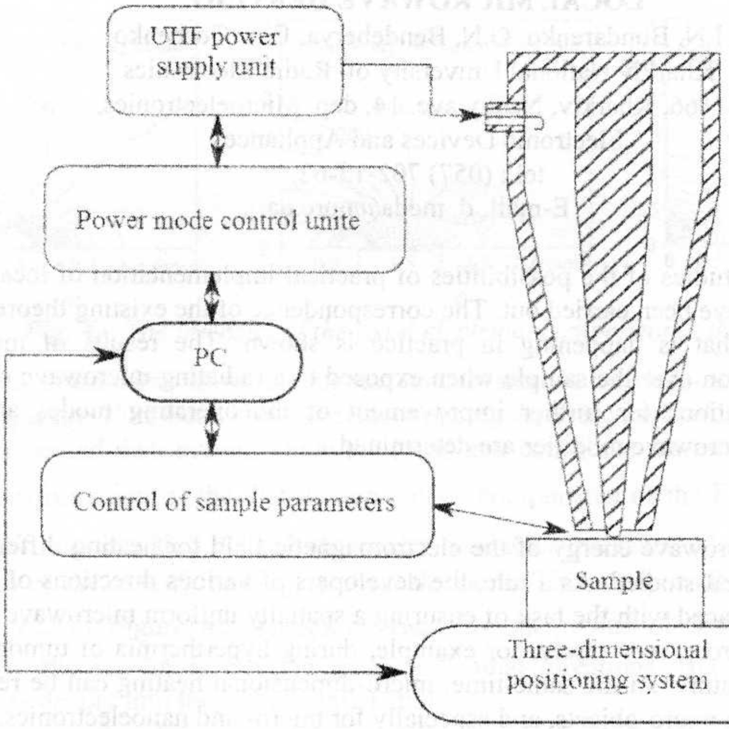


***Fig. 1** – Functional diagram of the microwave micromodifier main nodes*

An installation, based on a magnetron type generator M-857 with a generation frequency of ~ 9.480 GHz with output power of up to 10 W, was assembled for experimental studies of microwave heating. A general view of the installation is shown in Fig.23. Fig. 3 shows a general view of the radiator with a tuning screw.

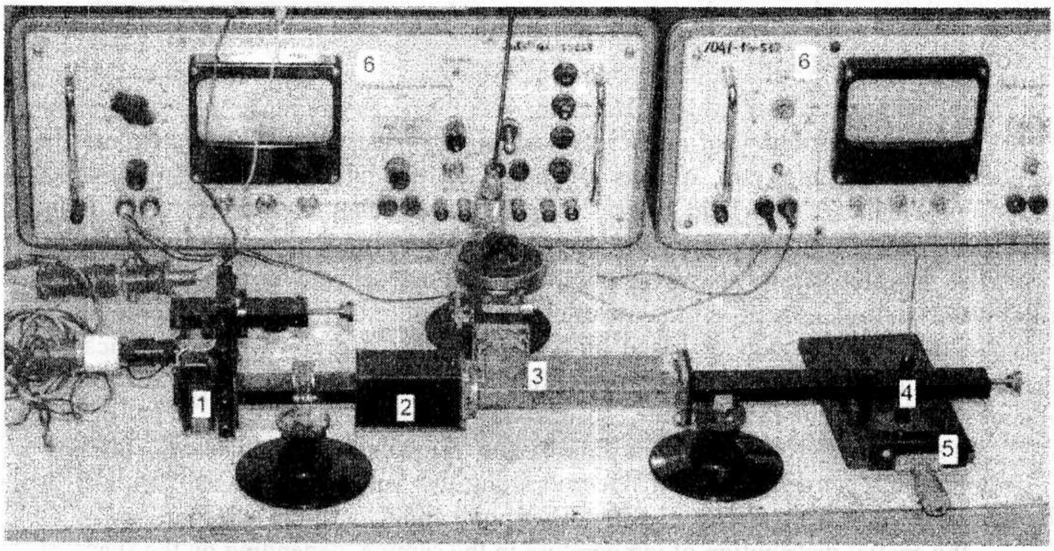


***Fig. 2** – Installation for formation of the local EMF power up to 10 W: 1 - M-857 magnetron, 2 - ferrite valve, 3 - directional coupler with attenuator and detector head, 4 - emitter (impact tool), 5 - objective table, 6 - power supply units of the magnetron*

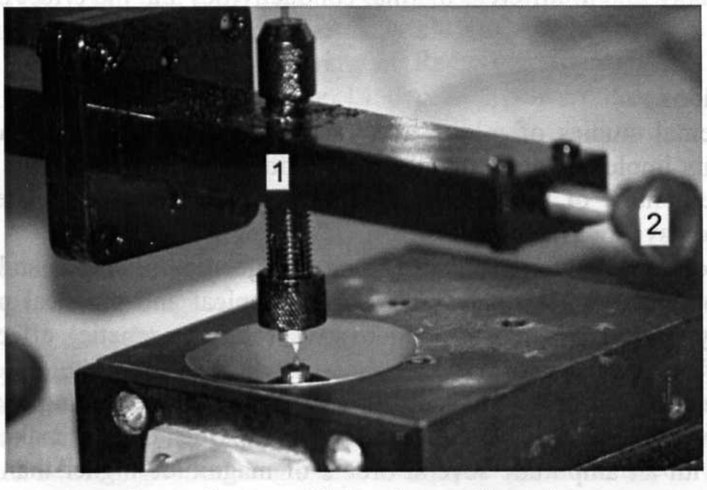


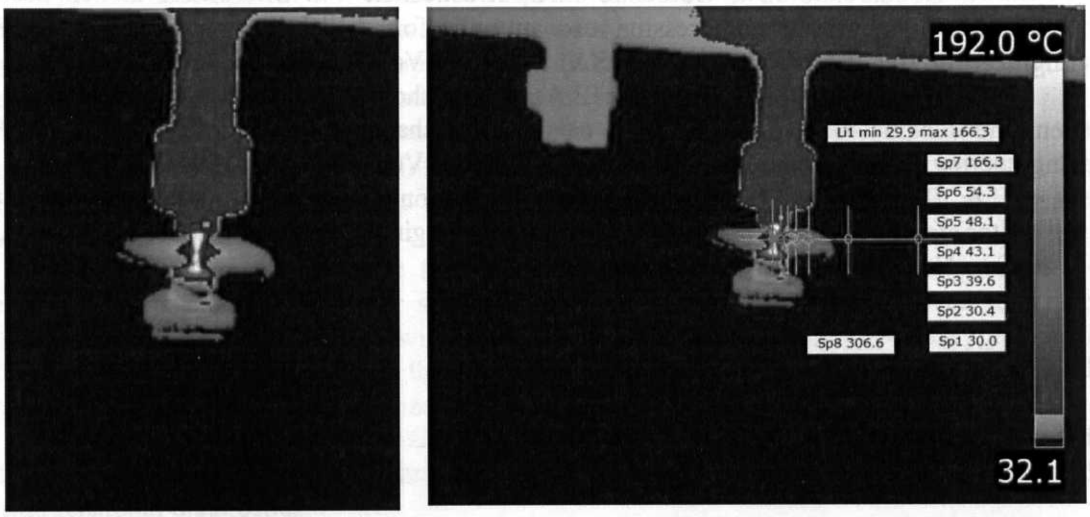
Fig. 3 – General view of the emitter with setting screw:
1 - waveguide-coaxial transition, 2 - short-piston setting screw

A gas discharge occurs at some ratios of the electric field intensity between the emitter and the object, the gap between them and the ambient pressure.

Substrates of monocrystalline silicon and polycore coated with a layer of photoresist were used as objects for studying the temperature distributions. Studies of thermal fields on substrates were carried out both in the mode of a probe touching their surface and in the mode of a plasma action with a gap.

The thermal distribution was recorded using a FLIR E60 type thermal imaging camera with a FOL17 lens. The temperature resolution of the camera is 0.05^0C. Thermal images were processed using the FLIR Quick Report 1.2 firmware.

Fig. 4 show the thermal fields in the field of view of the camera (a) and the temperature at the points of the substrate (b), which are located along the radius of the region centered on the tip of the working probe (Sp1 ... Sp7), the probe tip temperature Sp8.



a б

Fig. 4 – Thermogram of the silicon substrate heating. Thermal field (a) and temperature at the points of the Sp1 ... Sp7 substrate, located along the radius of the region centered on the tip of the working probe Sp8 (b)

In all cases, the effect of microwave power was constant, without modulation in time of exposure. The nature of the distribution is generally the same with slight differences in steepness, probably due to different thermal conductivities and the effect of photoresist on heat distribution.

Conclusions.

Experimental studies of microwave local heating confirm the main provisions of the conditions for its implementation, obtained by model consideration. This leads to the need to take into account most of the factors identified by the simulation, when implementing the process of microwave local heating.

If the requirements for positioning and the geometric shapes and sizes of nodes and elements can be met with the help of existing technical and practical possibilities, then the questions of dynamic control of the microwave (electromagnetic) effect process imply the development of special support.

In this regard, it seems promising to use devices for generating amplified pulse signals based on microwave resonator storage devices [28–30]. Such devices make it possible to receive pulse signals with an amplitude several orders of magnitude higher than the generator signal from generators of continuous microwave radiation of low power and to

Integrated use of the available theoretical and experimental results allows us to raise the question of the possibility of creating technological devices for microwave local effects on small-sized objects and structures, including those ones of the micro- and nano-level.

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