ABSTRACT

Dubinin M. M. Formation, diagnostics and control of the radiation of focused terahertz laser beams. Qualification scholarly paper: a manuscript.

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The thesis is devoted to theoretical and experimental studies of the physical laws of the formation, focusing of wave laser beams of continuous terahertz radiation with inhomogeneous spatial polarization and control of the radiation of focused laser beams. To solve these problems, the methods of modern radio physics, computational electrodynamics and mathematical physics were used.

The performed literature review shows that a new scientific direction is actively developing in quantum radiophysics associated with the formation of spatially inhomogeneous modes with the required polarization state, as well as with focusing and control of these modes. In the optical range, both intra-resonator and extra-resonator methods for forming output beams with a given polarization state are proposed. However, they don't provide a complete and complex solution to problems and are characterized by a sufficiently high complexity of manufacturing laser systems and, accordingly, their cost. Intra-resonator methods require the introduction of complex additional optical elements into the resonator to ensure the formation of modes with spatially inhomogeneous polarization, and extra-resonator methods are highly sensitive to a given initial radiation profile. Methods and approaches for the formation of laser beams with the necessary polarization structure in the terahertz (THz) range are developed only in a few works, and all of them belong to the extra-resonator group of methods proposed using pulsed radiation.

In the optical range, the physical principles of focusing laser beams with inhomogeneous spatial polarization of radiation are established. The possibility of controlling light fields with subwavelength sizes of energy localization regions is

shown. For the THz range, the properties of focused laser beams with inhomogeneous spatial polarization have been studied in only a small number of works. In these works, the radiation of mW generators of broadband subpicosecond pulses of femtosecond lasers was investigated. The interaction of such radiation with matter differs significantly from the interaction with continuous radiation. This approach leads to a rather high complexity of manufacturing laser systems. To expand the possibilities of scientific and technical applications, it is urgent to study the intensity distributions in the focal region of a focusing system for various types of inhomogeneous spatial polarization of continuous THz radiation.

Therefore, in the second chapter of the dissertation work, a calculation method was proposed and quantitative indicators were obtained for the reflection and transmission coefficients of waveguide modes for a diffraction mirror in the form of a large-scale multi-ring diaphragm. This mirror was located inside a hollow circular dielectric waveguide. On this basis, for the first time, it was proposed, theoretically substantiated and experimentally confirmed a method for the formation of a separate transverse mode with azimuthal polarization of the field in a laser resonator of the THz range, based on the implementation of one of the mirrors of the waveguide quasi-optical resonator in the form of a dielectric layer with an azimuthally symmetric metal large-scale diffraction grating.

For the first time, a semitransparent azimuthally symmetric small-scale diffraction mirror without outer circles has been proposed. This mirror selects unwanted modes and forms the desired mode with the azimuthal polarization of the radiation. However, it has been experimentally proved that this mirror has a lower energy efficiency compared to a semitransparent small-scale diffraction mirror with an antireflection center.

For the first time proposed, theoretically substantiated and experimentally confirmed a method for the formation of the highest EH_{12q}-mode in a laser resonator, based on the placement of a scattering groove with a width of 2.3-2.8 λ on the surface of one of the mirrors of a waveguide quasi-optical resonator. This makes it possible to significantly increase the losses for all undesirable modes, and to leave the losses for the higher EH_{12q}-mode practically unchanged, which ensures its preferential excitation.

For the first time, a method for forming a transverse TM_{01q}-mode with radial polarization of radiation at the output of a laser with a translucent radially symmetric diffraction mirror with a center that reflects the radiation is proposed and experimentally confirmed.

The third section of the dissertation is devoted to the determination of the physical features of the space-energy characteristics with moderate and tightly focusing in free space of radiation beams with different spatial polarization of the field excited by the modes of a laser resonator based on a hollow circular dielectric waveguide. It has been shown theoretically and experimentally that for a radially polarized TM_{01}-mode with tightly focusing of radiation in the field distribution, a significant increase in the axial intensity is observed, which is due to an increase in the contribution of the longitudinal field component to the total intensity of this mode, which is absent at moderate focusing. It is shown that the linearly polarized EH_{11}-mode has a maximum field on the beam axis for both types of focusing. With tight focusing, the focal spot of this mode has the smallest diameter.

The spatial-energy characteristics of radiation beams with different spatial polarizations of the field excited by the modes of a THz laser resonator based on a hollow circular metal waveguide are theoretically investigated for moderate and tight focusing in free space. For the first time, it was established that the asymmetric TE_{11}-mode has the maximum field on the beam axis for both types of focusing, as well as the smallest diameter in the focus.

In the fourth section of the dissertation work, the possibility of controlling the parameters of the focal region of tightly focused laser radiation beams excited by the modes of a THz laser resonator based on a hollow circular dielectric waveguide is studied theoretically and experimentally for the first time. The proposed focusing system in the form of a short-focus lens, the central area of which was overlapped by absorbing masks of various diameters. It is shown that the use of absorbing masks makes it possible to reduce the beam diameter in the focal region and significantly increase the depth of focus of the linearly polarized EH_{11}-mode and azimuthally polarized TE_{01}-mode.

The methods and schemes of formation and selection of transverse modes with different spatial polarization of the field in waveguide quasi-optical resonators proposed and studied in the dissertation can be used in the development and creation of new designs of laser systems with controlled characteristics for scientific and applied research - single-mode lasers with a given shape and polarization of the initial beam.

The results of laser beam focusing studies can be used to solve problems related to the interaction of electromagnetic waves with matter: diagnostics of the surface of materials, thin films, biological objects, achieving subwavelength resolution of THz tomography, for radar and telecommunications applications, etc.

The proposed method of controlling tightly focused laser beams can be applied in such applications as obtaining terahertz images (including extended objects), laser ablation, and optical discharge generation, where focusing of terahertz radiation with an increased depth of focus is necessary.

Keywords: terahertz range, waveguide laser, continuous radiation, beam formation, inhomogeneous mirror, inhomogeneous polarization, dielectric resonator, metal resonator, focusing, mode, radiation control.