Propagation and focusing of modes of the dielectric resonator of terahertz laser

O.V.Gurin, A.V.Degtyarev, V.A.Maslov, V.S.Senyuta, V.A.Svich, A.N.Topkov
V.N.Karazin Kharkov National University, Department of the Quantum Radiophysics
Svobody Sq. 4, Kharkiv, 61022, Ukraine
v.a.maslov@mail.ru

***Abstract*— Theoretically on the basis of the vectorial Rayleigh-Sommerfeld theory and experimentally using terahertz radiation of the waveguide laser (λ = 0.4326 mm) the physical features of propagation and "moderate" or "sharp" focusing of laser beams of radiation are investigated in free space which described by modes of circular hollow dielectric waveguide with different spatial polarization.**

Keywords*— *propagation; focusing; terahertz laser; dielectric resonator, modes.

The purpose of this work is to study features of the structure of the field of waveguide modes for the dielectric resonator of the terahertz laser in the near- and far-field of diffraction and their focusing for various types of spatial polarization of these modes.

I. Theoretical relationships

Let us assume radiation is given in the initial plane in the form of symmetric azimuthally, radially and linearly polarized TE_{01}, TM_{01}, EH_{11} modes and asymmetrical linearly polarized $TE_{01}+EH_{21}$ mode of circular dielectric waveguide. Components of electromagnetic fields for these modes have well-known form. We described the components of the vector of electric field using the Rayleigh-Sommerfeld integrals and obtained the expressions for the transverse and longitudinal components of the field in the free space in different zones of diffraction and in the focal plane of the lens.

II. Results and their discussion

The wavelength of radiation was selected in the middle part of terahertz range λ = 0.4326 mm (generation line of laser with optical pumping on molecule CH_3OH). For comparison of spatial characteristics of the studied modes and modes of free space it was analyze the propagation in free space linearly polarized axially symmetric Gaussian beam with a radius equal to the radius of waveguide EH_{11} mode at the e^{-2} level of its maximum value at the output end of the waveguide.

The transverse intensity distributions of the components of the electric field vector and the total field intensity of radiation beams were studied for the investigated waveguide modes in the field of minimum size of the focused beam. Focal length of the lens is selected suitably conditions of “moderate” (numerical aperture NA ≤ 0.7) and “sharp” (NA ~ 1) focusing.

III. Conclusions

We have established that the stable structure of the field is observed for TE_{01}, TM_{01}, EH_{11} and $TE_{01}+EH_{21}$ modes in the terahertz range at shorter distances from the end of waveguide ($L \geq 2a^2/\lambda$) in contrast to the distances predicted by known Rayleigh criterion ($L \geq 8a^2/\lambda$) for far-field zone of diffraction.

Numerical simulations show that in the case of "moderate" and "sharp" focusing for the intensity of the components of a vector of an electric field and the total field in the focus of the lens the following physical features are observed:

– the transverse E_x-component of the field has a maximum value of the intensity for TE_{01} and TM_{01} modes;

– the maximum intensity value for the transverse E_y component of field is observed for the EH_{11} mode and the minimum value is for the TE_{01} and TM_{01} modes;

– the longitudinal E_z component of a field has its maximum value of intensity for TM_{01} mode. However, if the NA ≤ 0.7, its value is less than 4 %, then the NA ~ 1, it increases to 40 % from the corresponding values for the transverse components. Significant growth of this component is also observed for EH_{11} mode – from 0.2 % at NA ≤ 0.7 to 6 % at NA ~ 1;

– the transverse intensity distribution of the longitudinal E_z component of a field for TM_{01} mode has the form of the sampling function but for EH_{11} mode it has annular character. The annular intensity distribution is observed for all components of the field for TE_{01} mode;

– the maximum value of the total radiation intensity is observed for EH_{11} mode and the minimum value for TE_{01} and TM_{01} modes;

– the diameter of the focused spot for EH_{11} mode is 1.5 times smaller than the diameter of the focused spot for other modes.

Experimental studies confirmed the conclusion that the maximum value of the total radiation intensity and the minimum diameter of the focused spot is observed for EH_{11} mode.