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TERAHERTZ RADIATION

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Modelling of output mirrors based on circular gradient structures for THz lasers

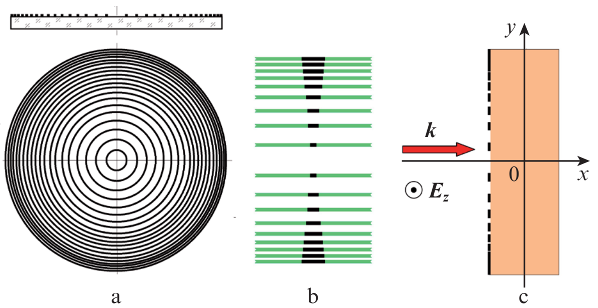
M.I. Dzyubenko, V.A. Maslov, E.N. Odarenko, V.P. Radionov

Abstract. **We substantiate the use of gradient periodic structures placed on a plane substrate and consisting of concentric metal rings with parameters varying in radial direction, as output mirrors for THz lasers. Using computer simulation, it is shown that, with a certain change in parameters, such a structure has the properties of a concave mirror and a focusing lens, which is of importance for output mirrors of THz lasers.**

Keywords: *terahertz range, azimuthal polarisation, gradient grating, output mirror of a laser resonator.*

Gradient periodic structures [1 – 6], with parameters varying in one or several directions, can change the amplitude, phase, and polarisation properties of electromagnetic radiation interacting with these structures, which can be used in various fields of technology. One of the promising applications of such structures is laser technology, where various periodic structures are traditionally used as output mirrors of terahertz (THz) lasers. In particular, a periodic structure in the form of concentric metal rings is promising, since it makes it possible to obtain azimuthally polarised laser radiation, when the electric field vector is perpendicular to the beam radius [7]. In this work, useful properties of azimuthal polarisation are substantiated, and it is found that the output mirror, more transparent in its central part, makes it possible to increase the lasing efficiency. In addition, a reduction of diffraction losses in the resonator leads to a significant increase in the efficiency of THz lasers, which can be attained by using concave mirrors which, however, are more difficult to manufacture than plane mirrors. Therefore, plane gradient structures with focusing properties are promising. The aim of this work is to develop and simulate plane periodic structures that, when exposed to azimuthally polarised laser radiation, have the properties of concave mirrors and focusing lenses.

A feature of periodic structures is that they introduce a phase shift into the electromagnetic wave, with the magnitude of the shift depending on the structure parameters [8]. The circular gradient periodic structure we have proposed [9] (Fig. 1a) consists of concentric metal rings located on a plane transparent substrate. The parameters of such a grating vary in radial direction, which leads to a change in the curvature of the phase front of electromagnetic waves reflected and transmitted through the grating. A method for simulating such changes is developed. It is assumed in the simulation that the circular grating consists of separate sectors in which the conductors are parallel. Two diametrically opposite sectors are used for the calculation, and it is conditionally supposed that the length of conductors is not limited (Fig. 1b). This makes it possible to determine phase changes in the diametrical direction by means of a proven method of calculating gratings consisting of parallel conductors.



a b c

Figure 1. (a) Gradient circular grating, (b) calculation model based on two diametrically opposite sectors, and (c) scheme of incidence of a plane monochromatic wave onto the gradient grating.

We have considered a grating with a diameter of 4 mm, consisting of 21 metal rings with a width of 20 μm and a thickness of 0.5 μm, which are located on a quartz substrate (dielectric constant $\varepsilon = 4.5$) with a thickness of 1 mm. The distance from the centre to the inner ring is 160 μm. In the direction away from the centre, the distance between the rings decreases with a step of 8 μm. Figure 1c shows a schematic representation of the gradient grating and the corresponding coordinate system. A plane monochromatic wave with polarisation along the *z* axis and wave vector ***k*** is incident on the structure in the positive direction of the *x* axis. Numerical calculations in the framework of a two-dimensional model were conducted using a freely distributed MEEP software package based on the FDTD method [10]. The calculation grid of the model contains 20 nodes per unit length (0.1 mm). The spatial distribution of the electric field amplitude scattered on the gradient grating is shown in Fig. 2. We can observe focusing both of

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M.I. Dzyubenko, V.P. Radionov A.Ya. Usikov Institute for Radiophysics and Electronics, National Academy of Sciences of Ukraine, ul. Akad. Proskura 12, 61085 Kharkiv, Ukraine;
e-mail: mid41@ukr.net, dzyubenko41@mail.ru;
V.A. Maslov V.N. Karazin Kharkiv National University, pl. Svobody 4, 61022 Kharkiv, Ukraine; e-mail: v.a.maslov@karazin.ua;
E.N. Odarenko Kharkiv National University of Radio Electronics, prosp. Nauki 14, 61166 Kharkiv, Ukraine; V.N. Karazin Kharkiv National University, pl. Svobody 4, 61022 Kharkiv, Ukraine;
e-mail: e.n.odarenko@gmail.com

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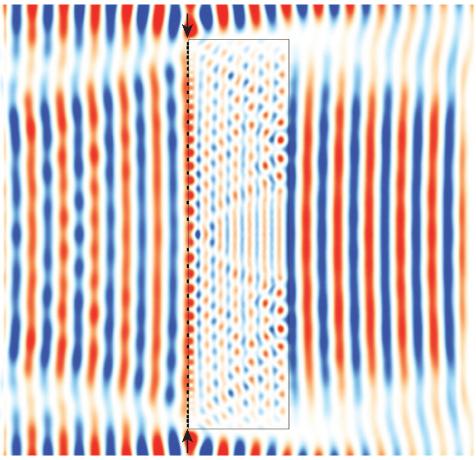

Figure 2. Amplitude distribution of the electric field strength.

the field passed through the structure and the field reflected from it.

To determine the phase profile of the scattered field, the real and imaginary parts of the electric field at the computational grid nodes were calculated. The calculation results are presented in Fig. 3. Curve (*1*) corresponds to the field reflected from the gradient grating. The phase front curvature leads to the radiation focusing similarly to the focusing by a metallic concave mirror with a curvature radius of 60 mm [curve (*2*)]. Curve (*3*) corresponds to the field passed through the structure. In this case, a more efficient focus is observed. Consequently, the circular gradient grating in question simultaneously performs the functions of a concave mirror and a focusing lens.

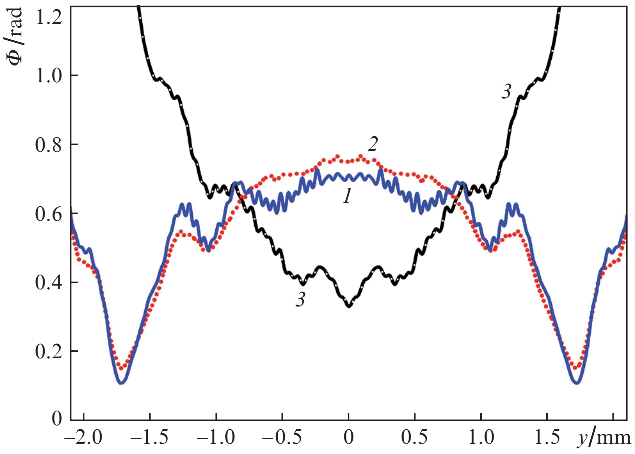

Figure 3. Transverse phase distribution of the electric fields: (*1*) reflected from the gradient grating; (*2*) reflected from the concave mirror; (*3*) passed through the gradient grating.

With the same difference in phase shifts at the edges and the centre of the circular grating, a greater phase front curvature can be obtained with a smaller outer diameter of the grating. With an increase in the outer diameter of the circular gradient grating, the minimum possible focal length also increases. In real THz lasers, the focusing achievable with the lens in question is quite sufficient to reduce the diffraction losses. It should be noted that, by setting a different sequence of changes in the periodicity of the circular grating, it is possible to obtain a wide variety of focusing properties. Obviously, with a reverse radial change in the gradient grating parameters, it can acquire the properties of a convex mirror and a scattering lens, which can also be used in practice.

As a result of the research, it was found that plane circular gradient gratings, whose fill factor increases from the centre to the edge, have the properties of concave mirrors and focusing lenses, which is promising for their use as output mirrors of THz lasers. Such mirrors make it possible to generate laser radiation with azimuthal polarisation and provide the required field caustic in the resonator, which allows one to reduce the diffraction losses and partially compensate for the output beam divergence. Increased transparency in the central part of the mirror enhances the lasing efficiency. The simulation technique presented facilitates the calculation of the properties of such periodic structures. Circular gradient gratings can be used in lasers of other ranges, and also in various devices, such as antenna reflectors.

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