Diffraction techniques for transformation of FEL beams*

Experiments at terahertz Novosibirsk free electron laser facility

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***Abstract*— Novosibirsk free electron laser is a tunable source of radiation generating high-power Gaussian beams in MIR, FIR and THz spectral ranges. In this paper we report the transformation of terahertz beams into the beams with prescribed cross-sections and phase distributions, including vector and vortex beams, using diffractive optical elements. Examples of the use of such beams in experiments are given in the paper.**

Free electron lasers, Terahertz wave technology, Diffraction, Vector and vortex beams, Talbot effect

Commonly used wide-band THz sources enable measuring both real and imaging parts of the refractive index of an object under study, but in many cases continuous wave sources are required. Free electrons lasers (FELs) generate coherent radiation in the ranges from x-ray to microwave. The main features of this lasers, high radiation power and the possibility of continuous wavelength tuning, make it possible to perform experiments at the forefront of science. The NovoFEL [1] is the most powerful radiation source in terahertz spectral range. Transformation of FEL radiation at the user stations into modes different of Gaussian one is often required in many studies. For example, a uniform irradiation of substances is necessary in biological experiments; beams with radial polarization may be required in experiments on the generation of plasmons on wires; pencil-like or "nondifractive" Bessel beams can be applied to radioscopy of extended objects, etc.

In the terahertz range, like in the X-ray range, there are no exist procurable spatial light modulators, which are used as phase or amplitude masks in the visible range, and other methods for beam transformation are required. Different sets of high-resistivity silicon binary diffractive optical elements (DOEs) were designed, fabricated and examined at the NovoFEL. The first ones transform Gaussian beam into Hermite-Gaussian and Laguerre-Gaussian beams of different orders [2]. Using combinations of these elements, some vector beams were formed. More sophisticated DOEs were designed to form the beams with determined areal or volumetric phase and intensity distributions. Binary axicons with spiral pattern of π-shifted zones and diameter up to 100 mm were fabricated. "Nondiffractive", self-healing Bessel beams with orbital angular momentum and topological charges $\pm(1-3)$ were formed [3] using the axicons. Difference between vortex Bessel beams formed with volumetric and binary spiral axicons was investigated. It was found that the last ones, at the expense of less diffraction efficiency, can form the beams in a wide spectral range, whereas the first ones can be employed only for a determined wavelength. The vortex beams were used in the experiments with surface plasmons [4] and to study "vortex" Talbot effect. It was first demonstrated that diffraction of vortex beams on 2D-gratings results in production of vortex beamlet arrays (Fig. 1).

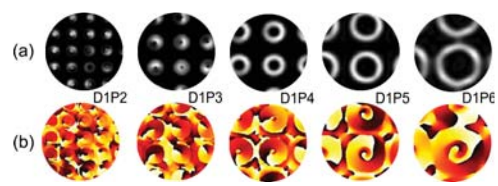

Fig. 1. Transformation of a linearly polarized Bessel vortex beam into an array of votrex beamlets via diffraction on 2D array of circular openings (D and P are hole diameter and grating period in mm, respectively): (a) intensity and (b) phase distributions in the Talbot plane $Z/2 = P^2/\lambda$.

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