Study of diffractive optical elements using high-power radiation of terahertz Novosibirsk free electron laser

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Abstract

Diffractive optical elements (polypropylene kinoform diffractive lenses, silicon binary diffractive lenses and silicon beam-splitters) for the terahertz spectral range have been designed and characterized using high-power terahertz radiation of the Novosibirsk free electron laser. Effect of an antireflection coating at the silicon elements was studied.

I. Introduction And Background

Diffractive optical elements (DOEs) are most beneficial for beam manipulation at THz frequencies. This statement is especially valid in a case of high-power terahertz beams, which damage conventional plastic lenses such as polypropylene or TPX ones. Such applications like holography, interferometry and polarimetry require dividing a beam into two beams of equal intensity. Other applications, like imaging, material ablation, generation of continuous optical discharge, and even more exotic for the terahertz range application, namely the field ionization of individual atoms, require focusing of THz radiation, often with a low *f* number.

In this paper we report characteristics of three types of diffractive optical elements: high-density polypropylene kinoform diffractive lenses (KDLs), silicon binary diffractive lenses (BDLs) and silicon beamsplitters (BSs). The first ones were designed and fabricated in TDISIE SB RAS. The other elements were produced by TYDEX, IPSI RAS and SSAU.

II. Experiments and Results

The experiments have been carried out using radiation of the terahertz Novosibirsk free electron laser (NovoFEL). The laser generated monochromatic radiation as a continuous stream of 100-ps pulses with a repetition rate of 5.6 MHz. The laser beam at the station had the Gaussian shape $I = I_0 \exp(-2r^2 / w^2)$ with a waist of $w = 9$ mm, which means that practically 100% of beam energy passed through a circle of 30-mm in diameter. Average power of radiation in the experiments was 50 – 100 W. All experiments have been carried out at λ=141 µm. The radiation having passed through the element under study was recorded with a microbolometer 320x240 2D array (MBA) with physical size of 16.32x12x24 mm moving with a motorized translation stage along the optical axis.

Polypropylene kinoform diffractive lenses. Two KDLs with the parabolic profile of Fresnel zones (designed with *f*=200 and *f*=80 mm for wavelength of λ=130 µm) were fabricated by hot pressure of high-density polypropylene. Because of small thickness, equal to 0.8 mm, and a low refractive index, they were practically transparent to THz radiation. To fit laser beam diameter to the KDL aperture (D = 80 mm) it was expanded by 2.5 times using a telescope with off-axis parabolic mirrors. We observed the main focus with a half-width of 0.23 mm for the *f*80 KDL at a distance of 77.6 mm. Besides, more three maxima on the axis with similar half-width were observed at 69, 59 and 51 mm (first order focus, which can be observed in accordance with theory at 25 mm, was out of scanning range). Power in these focuses was of 23%, 5% and 1% relatively to the main focus.

Binary diffractive lenses. BDL was a two-level diffractive lens with a diameter of 30 mm (f = 120 mm, λ=130 µm). Fresnel zones have been etched on a high-resistivity one-mm thick silicon plate. We observed two focuses at a distance of 121 and 42 mm with excellent agreement with theory. The diffraction efficiencies were 17% for the main focus and 2.4% for the secondary focus. For the BDL with antireflecting coating they were 40% and 3.6%, respectively.

Beamsplitters. A beamsplitter of 30-mm in diameter with a rectangular grating etched on silicon plate and a TPX lens with the focal length of 50 mm were placed across the laser beam. Image in the focal plane was recorded with the MBA. Distance between zero order and first order focal points enabled to measure diffraction angle of the grating which appeared to be 15^0.

It is worth pointing out that FWHM of the focal spots for 140 µm were 0.33 mm for *f*50 TPX lens, 0.76 mm for the BDL, and 0.23 mm for KDL.

The experiments have demonstrated feasibility of application of different kinds of DOE for manipulation of low- and high-power terahertz radiation.

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