Study of Diffractive Optical Elements Using High-Power Radiation of Novosibirsk Terahertz Free Electron Laser

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***Abstract*— Diffractive optical elements (polypropylene kinoform diffractive lenses, silicon binary diffractive lenses, and silicon beamsplitters) for the terahertz spectral range have been designed and characterized using high-power terahertz radiation of Novosibirsk free electron laser. The effect of an antireflection coating on 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 true for high-power terahertz beams, which damage conventional plastic lenses such as polypropylene or TPX ones. Such applications as 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 those more exotic for application in the terahertz range, namely field ionization of individual atoms, require focusing of THz radiation, often with a small focal length.

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 at TDISIE SB RAS. The other elements were produced by TYDEX, IPSI RAS, and SSAU.

II. Experimental Results

A. Radiation source and imaging device

The experiments were carried out using radiation of Novosibirsk terahertz free electron laser (NovoFEL) [1]. The laser generated monochromatic radiation as a continuous stream of 100 ps pulses with a repetition rate of 5.6 MHz. At the station, the laser beam was of the Gaussian shape, $I = I_0 \exp(-2r^2/w^2)$, with the waist $w = 9$ mm, which means that practically 100% of beam energy passed through a circle of 30 mm in diameter.

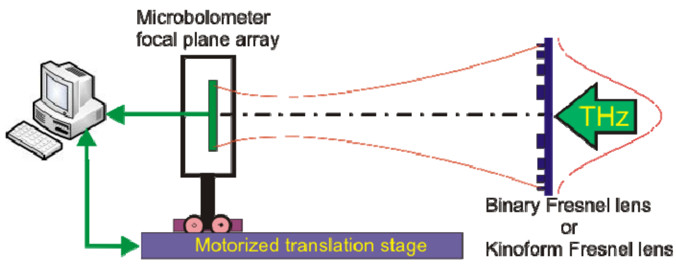

Fig. 1. Experimental setup.

The average power of radiation in the experiments could be varied from 5 to 100 W. All experiments were carried out at λ=141 µm. One of the experimental configurations is shown in Fig. 1. Radiation that passed through the element under study was recorded in real time with a 320x240 microbolometer 2D array (MBA) with physical dimensions of 16.32x12x24 mm, moved by a motorized translation stage along the optical axis.

B. Polypropylene kinoform diffractive lenses

Two kinds of high-density polypropylene KDLs with a parabolic profile of Fresnel zones (designed with *f*=200 and *f*=80 mm for the wavelength λ=130 µm) were fabricated by hot pressure imprinting with a metal master (Fig. 2). A similar eight-level polypropylene KDL imprinted with a silicon master, with a diameter of 25 mm and a focal length of 50 mm, was described in [2]. Because of the small thickness

(0.8 mm) and low refractive index, they were practically transparent to THz radiation. For the laser beam diameter to match the KDL aperture (*D* = 80 mm), the diameter was expanded 2.5 times using a telescope with off-axis parabolic mirrors. Intensity distribution along the caustic for the three samples of KDLs (f = 80 mm) was recorded with a scanning distance of nearly 80 mm. For the KDL with *f*=80, we observed a fundamental focus with a half-width of 0.23 mm at a distance of 77.6 mm. The first-order focus, which in accordance with the theory could be observed at a distance of 25 mm in case of mechanical inaccuracy of Fresnel zones fabrication, was not detected because of geometrical restrictions of the MBA design. Intensity distributions were absolutely identical for all the samples. No damage caused by the high-power radiation was detected. These lenses are commonly used in optical systems at the NovoFEL user stations [3].

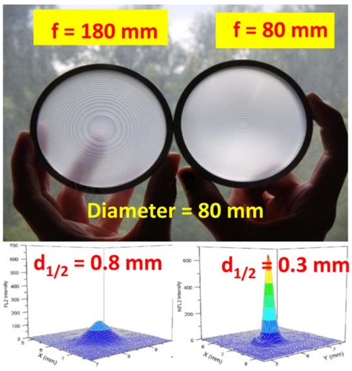

Fig. 2. Polypropylene diffractive lenses and power density distribution in their focuses.

C. Silicon binary diffractive lenses and beamsplitters

Binary (two-level) diffractive optical elements were formed on polished substrates of high-grade silicon HRFZ-Si [4] with a diameter of 100 mm and a thickness of 1 mm. A standard photolithographic process followed by plasma-chemical etching was used for DOE manufacturing. The reactive ion etching (RIE) described in [5] was applied for creation of a microrelief profile with a large height (about 30 microns) and walls with small deflection from the vertical. The diffractive microrelief was etched on a surface of a high-resistant silicon plate 1 mm thick. Similar techniques with deep reactive ion etching and multilevel resist processing were used in [6]. A microfabrication technique using a gray-scale mask was applied in [7].

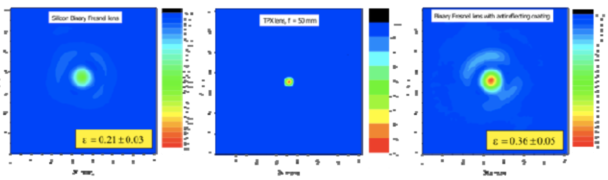

Fig. 2. Intensity distributions in the focal plane of BDLs in comparison with the focus of the TPX lens with *f* = 50 mm.

Binary (two-level) diffraction lenses with a diameter of 30 mm) were designed with *f* = 120 mm @ λ=130 µm. We observed two focuses at distances of 121 and 42 mm in excellent agreement with the theory. The diffraction efficiencies were 21±3 % for the main focus and 3% for the secondary focus. For a larger diffraction efficiency, the lens was covered with a λ/4 Parilene C layer [8, 9]. For the BDL with an antireflection coating they were 36±5 % and 3.6%, respectively.

A beamsplitter of 30 mm in diameter with a rectangular grating etched on a silicon plate and a TPX lens with a focal length of 50 mm were placed across the laser beam. The image in the focal plane was recorded with the MBA. The distance between the zero-order and first-order focal points enabled us to measure the diffraction angle of the grating, which appeared to be 15^0. The radiation resistance of the Parilene C layer was examined by focusing radiation on the layer. The absolute power density was measured using a thermal sensitive Fizeau interferometer [10]. The layer was not damaged under exposure to radiation of an average power of up to 4 kW/cm^2.

III. Conclusion

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

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