DIFFRACTION OPTICAL ELEMENTS AND OPTICAL SYSTEMS WITH A HIGH POWER MONOCHROMATIC TERAHERTZ SOURCE *

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Abstract

We have developed reflective diffraction optical elements (DOE) for focusing radiation of terahertz free electron lasers (FEL). Metal-dielectric Fresnel zone plates and metallic kinoform "lenses" were fabricated and tested using FEL radiation. A microbolometer camera (see the paper by Esaev et al. at this conference) sensitive to THz radiation had been applied for recording both terahertz beam caustic and terahertz images. Diffraction efficiency of a kinoform lens appears to be about unity. Quality of images obtained with the kinoform lens was studied. The lens was used as a key element for a Toepler optical system, which were used for studying condense matter non-uniformities and deformations. The experiments were performed at Novosibirsk and KAERI FELs.

INTRODUCTION

Imaging in the terahertz spectral region (1 – 10 THz) is a subject of special interest for many applications such as biological researches, medical diagnostics, study of materials, security systems and many other applications. Each optical system consists of a source of radiation, optical elements and an imager. In this paper we describe optical elements and recorders developed for imaging with free electron laser (FEL) as a source. Most of the experiments were carried out at high power Novosibirsk FEL. Some of them have been done at KAERI FEL.

Because the refractive optical elements can be damaged by high power terahertz radiation, we have developed a number of reflective diffraction optical elements (DOE). Large-scale reflection DOE are often used in the microwave spectral region, and the application of DOE in terahertz optical systems is, obviously, very prospective.

Previously [1 – 3] we have developed (or adapted) three recorders for the visualization of intense terahertz radiation: a near-IR thermograph, a thermal-sensitive Fizeau interferometer, and a "thermal image plate". In this paper we first used as a terahertz imager [4] a microbolometer matrix, initially developed for the MIR range 0. The matrix has higher sensitivity and better spatial resolution, than the imagers mentioned above.

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TERAHERTZ OPTICAL ELEMENTS AND SYSTEMS

Fresnel zone plates

Three Fresnel zone plates (with zone numbers of 91, 46, and 30, respectively, and the first Fresnel zone radii of 5.2, 7.35 and 9.0 mm) had been designed and fabricated for focusing terahertz radiation with simultaneous reflection under the right angle. The elliptically shaped plates with the minor semi-axis of 5 cm and the aspect ratio of 1:1.41 were formed by etching a copper foil clad on a fiber-glass plastic. The central zone of each plate was reflecting.

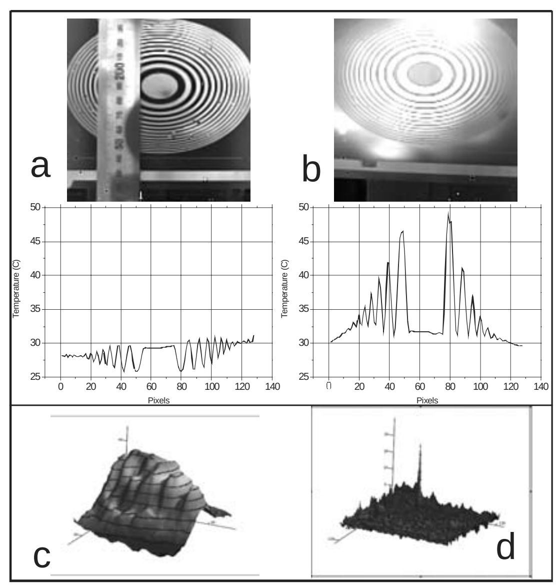

Figure 1: A thermographic image of a zone plate recorded with no radiation (*a*) and with THz irradiation (*b*); plots – effective temperature distribution along the major ellipse axis. Intensity distribution in the initial THz beam (*c*) and in the zone plate focus (*d*) recorded with the thermal image plate.

The images of a zone plate taken at 2.5 – 3.0 μm with the thermograph (Fig.1) show growing the temperature of the dielectric zones up to 55 C, nevertheless, the zone plate focuses THz radiation well. The focal lengths for all zone plates exactly correspond to designed values. Since the principle focal length of a zone-plate is inversely proportional to the radiation wavelength, $f_1 = r_1^2/\lambda_0$, it can be used at arbitrary wavelength, but low diffractio efficiency (~10%) constrains its application.

Reflecting kinoform lens

More effective in comparison with a zone plate is a kinoform or Fresnel lens, in which each zone surface is parabolically profiled. First, we tested a simplified kinoform lens with elliptical zones, similar to the above described zone plates, and with the profile designed for focusing radiation at $\lambda_0 = 130$ μm with $f = 250$ mm. The kinoform lens was manufactured by drilling on a NC machine. Minor radius of the first Fresnel zone was equal to 8.06 mm. Measured diffraction efficiency of the lens appears to be close to unity.

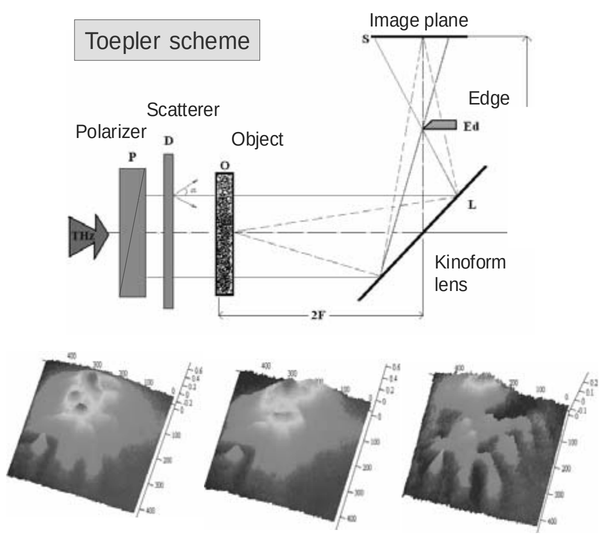

Figure 2: Toepler optical system and images obtained for a polyethylene film as an object: undistorted film (left picture) and stretched ones.

Optical systems with kinoform lenses

The kinoform lens was used as a focusing element in a Toepler quasi-optical system (Fig.2) intended for the study of loaded solid samples and stretched films by means of terahertz radioscopy. Experiments were performed both at NovoFEL and KAERI FEL. Dynamic range and linearity of Toepler system response critically depend on the focal spot quality. Using a 160×120 pixel, 51 μm period microbolometer focal plane array 0, we recorded the distribution of terahertz radiation intensity (Fig. 3) in the caustic surface of the elliptical kinoform lens without scatterer, object and knife-shaped edge.

The kinoform lens has a relatively small focal spot size in the vertical direction (at $L = 250$ mm), which enables using the lens for the study of vertical optical path gradients, but the horizontal spot size is too large and the intensity distribution is uneven, which does not enable measurement of horizontal nonuniformities. The origin of the horizontal focal spot distortion lies, obviously, in the simplified Fresnel zone and surface shapes. The correct shape must be an emulation of the off-axis parabolic mirror that is not easy to fabricate.

To obtain a good focal spot, we fabricated axisymmetric kinoform lens, and by inclining it under a small angle, extracted the reflected terahertz radiation onto a small plane mirror that enabled displacing the focal spot out of the initial beam. 2D surface plot in Fig. 3 demonstrates high quality of the focal spot for the axisymmetric kinoform lens.

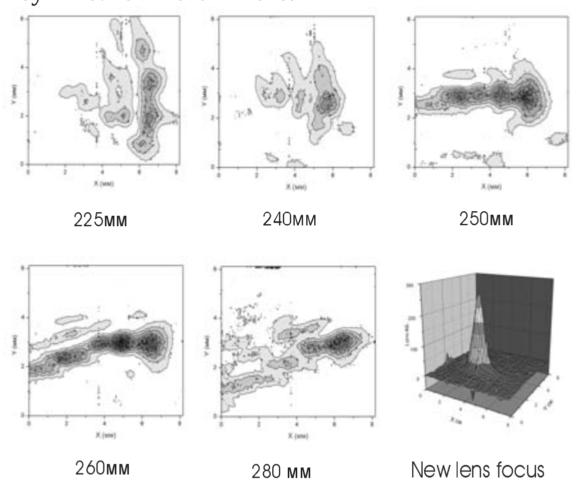

Figure 3: Distribution of terahertz beam intensity in the elliptical kinoform lens caustic surface (2-D plots) and in the focus of axisymmetric kinoform lens (the last plot) recorded with the microbolometer focal plane array.

CONCLUSION

Focusing elements and detectors developed in this study enable designing of quasi-optical systems for imaging and radioscopy with a high power terahertz free electron laser. Examples of optical path gradients recorded when THz beam passed through stretched polyethylene film are shown in the bottom Figure 2.

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