3D printed flat optics and InP Heterojunction Bipolar Transistor based-detector for THz imaging

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***Abstract*—Diffractive optical elements such as hyperbolic lens and quasi-spherical lens converting a divergent terahertz beam into the focal line segment perpendicular to the optical axis was designed. Due to the fact that the length of the line segment was longer than the aperture of the designed elements the non-paraxial approach was used. The structures were designed for the narrowband application as kinoform elements. The theoretical approach, computer simulations and experimental results are presented. In the imaging system, the intensity of the radiation in the focal plane was measured by THz point-like detector based on InP heterojunction bipolar transistor.**

I. INTRODUCTION

THE most of terahertz (THz) sources provide point-like illumination, whereas the rapid scanning requires lines or matrices of detector arrangements. Therefore, optical elements (e.g. lenses) are required to shape the illuminating THz beam. Taking into account existing THz scanning systems it is necessary to apply sophisticated THz optics collimating and shaping the illuminating radiation. Evidently, different beam forming will be necessary depending on the specific detector arrangements: square arrays, single or multiple lines or simple point detectors for raster scanning systems.

In this work we use our previous experience in the domains of printed, flat diffractive optics [1-2] to construct diffractive elements that shape the illuminating divergent beam coming from the point-like source into a line in the focal plane. In particular we demonstrate the fabrication of hyperbolic lens and (together) quasi-spherical lenses and conduct experiments confirming that proposed THz optical system properly collimates and shapes the illuminating radiation into a focal line segment at the narrowband 0.3 THz, atmosphere transparency window. We have also shown that our flat hyperbolic lenses can already be used in realistic imaging system including point-like detector based on InP heterojunction bipolar transistors (InP HBTs).

II. TECHNOLOGY AND EXPERIMENTAL SET UP

The diffractive element was manufactured by means of 3D printing from polyamide 12 (PA12), which at the frequency of 0.3 THz has the refractive index n = 1.64 and the absorption coefficient 0.27 cm-1. The active area size was 100 mm x 100 mm (Fig. 1).

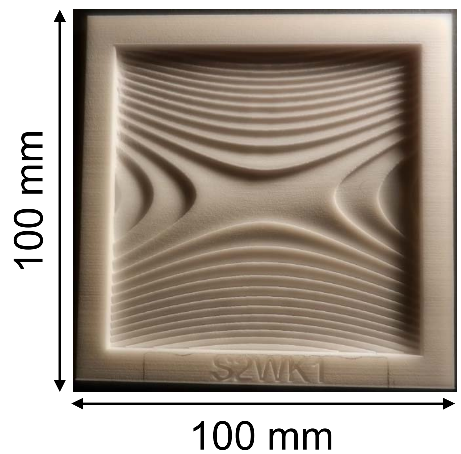

Fig. 1. The photograph of the designed diffractive element manufactured by 3D printing technique.

The optical setup used in the experiment is shown in Fig. 2. The electronic source based on Schottky multipliers was used to generate 0.3-THz radiation. The designed diffractive element (size 100 x 100 mm) was placed at a distance 200 mm behind the pinhole. It focused this wave-front into a line segment perpendicular to the optical axis at a distance 200 mm. The intensity of the radiation was measured by THz point-like detector based on InP HBT [3,4]. In the first experiment, the raster scanning technique was used and the detector was moved in the focal plane of the hyperbolic lens using the computer controlled step motor system. In the second experiment, to show that the hyperbolic lens is already exploitable for large-area fast imaging, a test object was moved along the Y-direction in the focal plane while the detector was moved in the X direction using motorized stages.

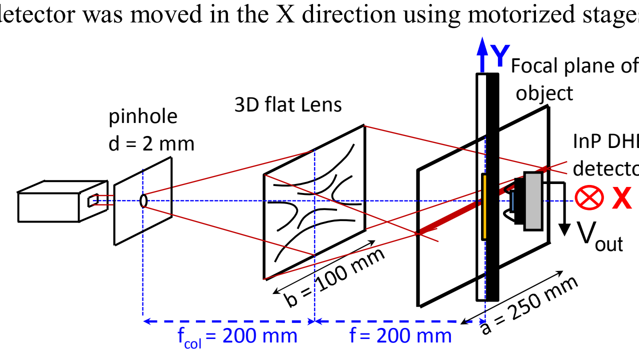

Fig. 2. THz imaging setup used to investigate the shape of the focal line. It is also used in the numerical modeling.

III. Results and Discussion

The intensity distribution in the focal plane is illustrated in Fig. 3a together with the cross-sections along (Fig. 3b) and across the focal line segment (Fig. 3c) of the 250-mm length. It shows that the designed element focuses the THz radiation coming from the pinhole into the line segment which is longer than the structure size b = 100 mm. The width is of 3 mm along the whole focal line segment, corresponding well to the numerical simulations reported in Ref. x. The non-uniformities and small deviations from theoretical model see in Fig.2c can be attributed to: the finite diameter of the pinhole (non-uniform illumination of the diffractive structure), the diffraction on the aperture edges of the designed element, imperfections of the structure resulting from fabrication errors and/or the attenuation of the medium.

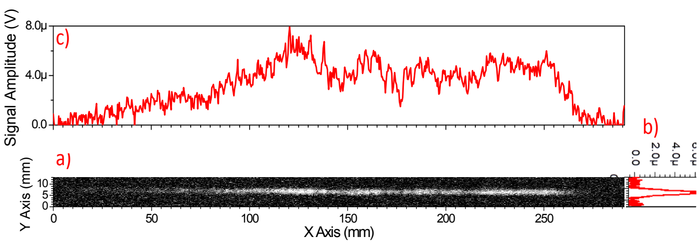

Fig. 3. The intensity distribution in the focal plane (a), the cross-section across (b) and along (c) the focal line segment.

The designed lens was also tested in the system of Fig. 1 with a single pixel InP HBT-based detector. The single pixel detector was raster scanned in the X direction, to reconstruct one line of the image of Fig. 4, while the object was moved in the Y direction at the end of each line. The obtained terahertz image illustrated a mirror (25.4 mm-diameter) hidden in its plastic box.

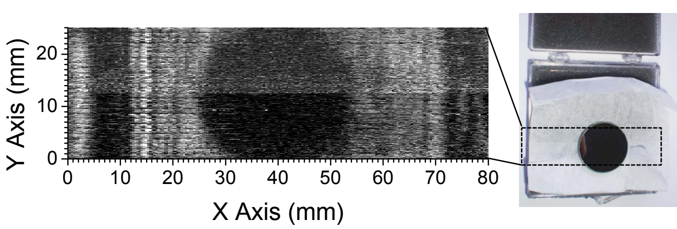

Fig. 4. Left: THz image in transmission mode of a closed box with a mirror inside, using a single diffractive optical element to convert a divergent THz beam into the focal line segment. right Visible image of the opened box.

IV. Conclusion

Concluding, the designed hyperbolic lenses works according to the assumed concept. It was determined that the parameters of the focal line segment fit the simulations. Experimental results prove that such optical element can be used in the illumination path of active THz scanners.

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