Influence of raster scan parameters on the image quality for the THz phase imaging in collimated beam with a wide aperture

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Abstract. We numerically investigated the influence of wavelength of terahertz radiation and size of scanning pinhole on the quality of reconstructed image by terahertz pulse time domain holography method. The improvement of the quality is achieved mainly by reducing the wavelength of the radiation, pinhole size and pinhole step (value of the pinhole displacement at each step) affect the spatial resolution of the reconstructed object and significantly affect the scanning time. However, pinhole does not significantly affect the quality only if pinhole size is not less than used wavelength.

1. Introduction

The technologies of terahertz (THz) imaging are important for many applications [1] because they allow to obtain more information about the object of investigation [2-3]. Terahertz pulse time domain holography (THz PDTH) is one of the perspective methods allowing imaging of both amplitude and phase objects [4]. One of the features of THz PTDH is the scanning of an object in a wide collimated THz beam. Experimentally this method is based on direct measurements of the spatial and temporal distribution of the THz field and extracting the phase information using Fourier analysis procedure and further reconstruction the phase delay on the object. The purpose of this work is the numerical investigation of the influence of image reconstruction parameters on the quality of the reconstructed object. For the numerical evaluation of the quality of THz PTDH method we used modulation transfer function (MTF) [5]. We investigated the influence of the size of the scanning aperture and the wavelength of the THz radiation on the contrast of the reconstructed image.

2. Numerical investigation of image reconstruction quality by THz PDTH

We have performed a numerical investigation of impact of setup parameters, such as wavelength and size of scanning pinhole, on the quality of amplitude object reconstruction. We investigated the dependence of MTF of reconstructed object on the size of the scanning pinhole and on THz wavelength. The distance between the object plane and the registration plane was fixed at 70 cm, the object size was fixed at 20x20 cm, pinhole size changed from 400 μm to 200 μm, spectral range was from 400 μm to 200 μm. As a sample we used periodic grating with a line structure (Figure 1a). Figure 1 shows reconstruction of the sample at wavelength 400 μm, 300 μm and 200 μm in case of pinhole size 400 μm. For the reconstructed images we calculated MTF and plotted the 3D dependence of contrast characteristics of reconstructed object. These dependences are for different pinhole sizes when fixed wavelength (Figure 2) and for different THz wavelengths when fixed pinhole size (Figure 3). In spectral range 200-400 µm pinhole size does not affect MTF significantly, but THz wavelength increases MTF.

3. Evaluation of a raster scanning time

THz wide collimated beam is raster scanned by square pinhole, which is fixed on the two coordinates controlled motorized translation stage. The motorized translation stage provides measurements of THz pulse temporal form at each step. Placing the object before the pinhole we obtained the spatial distribution of temporary forms of THz field, taking into account the phase shift during the passage of the THz field through the phase object.

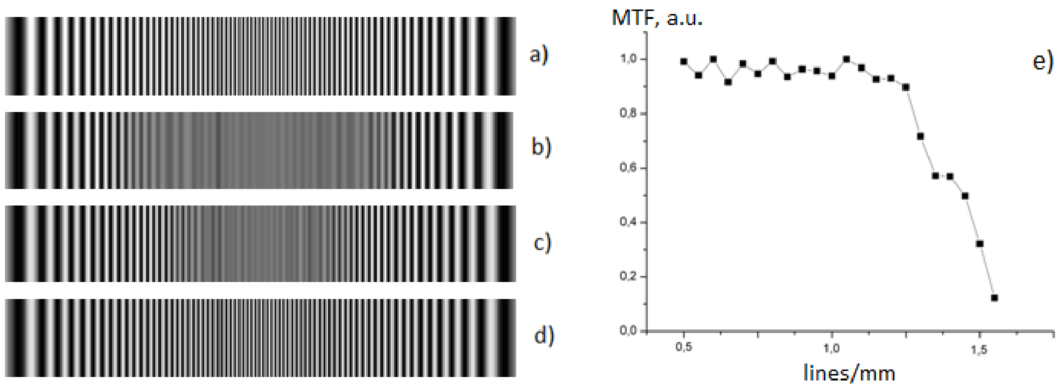

Figure 1. a)- cross section of initial object, b)- cross section of reconstructed object at wavelength 400 µm, c)- cross section of reconstructed object at wavelength 300 µm, d) cross section of reconstructed object at wavelength 200 µm, e) MTF function for (c).

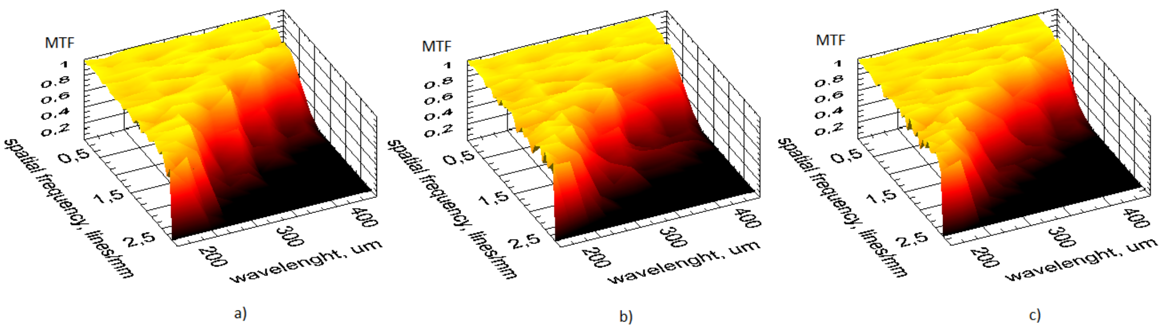

Figure 2. 3D dependence of MTF of reconstructed image from the wavelength when fixed pinhole size. a) pinhole size 200 µm, b) pinhole size 300 µm c) pinhole size 400 µm.

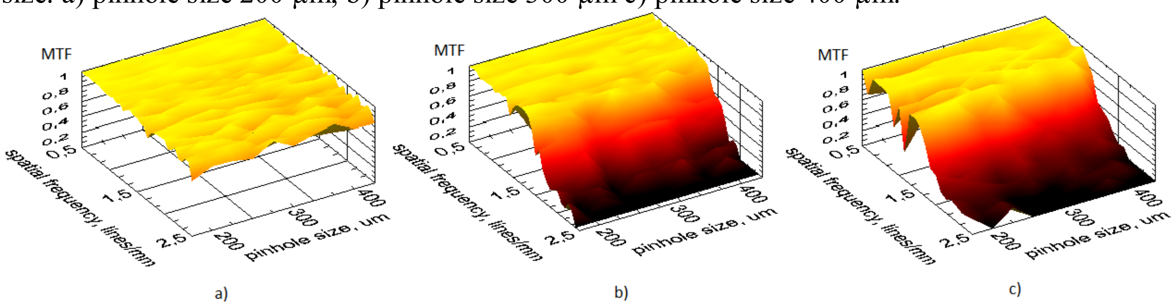

Figure 3. 3D dependence of MTF of reconstructed image from the pinhole size when fixed wavelength. a) 200 µm, b) 300 µm, c) 400 µm

In general, the time spent on scanning can be estimated as follows:

$$T_{scan} = \left(\left(\frac{L_z N_x N_y}{V_{z+}} + \frac{L_z N_x N_y}{V_{z-}} \right) + \left(\frac{\xi \cdot A_p \cdot N_x N_y}{V_{x,y}} \right) + T_{wait} \right) \cdot N_{mean} \quad (1)$$

where L_z - movement distance of translation stage by *z*, N_x - number of scans by *x*, N_y - number of scans by *y*, V_{z+} - forward movement speed of the translation stage by *z*, V_{z-} - backward movement speed of the translation stage by *z*, A_p - pinhole size, ξ - pinhole shift factor which determines the displacement of pinhole at each step relative to the pinhole size, $V_{x,y}$ - movement speed of the translation stage by *(x,y)*, T_{wait} - waiting time of the translation stage, N_{mean} - number of repetitions on each scanning step.

Reducing the raster scan time is possible when: 1) using involute stage [6] 2) reducing the number of steps in *(x,y)* scanning grid, 3) moving the translation stage in *(x,y)* grid while back movement by *z* axis, 4) reducing the temporal window for THz pulse by reducing the length of the displacement of the translation stage, however that leads to the loss of spectral information about the THz pulse, 5) increasing the speed of the translation stage, however it can reduce signal-to-noise ratio (SNR), 6) reducing the number of measurement repetitions at each scanning step, but it is only useful in case of a high SNR, 7) using single meaning measurement during slow movement by *z* instead of increasing the total number of repetitions N_{mean}, 8) using multichannel balanced electro-optic detection [7], or IR camera or array of microbolometers as a registration system.

4. Conclusion

We investigated parameters that affect the scanning time and the quality of image reconstruction. Based on these parameters we can optimize the experimental setup for THz PTDH. Improvement of MTF of reconstructed object has been achieved mainly by reducing the wavelength of radiation used in the image reconstruction. Pinhole size affects the spatial resolution of the reconstructed object and significantly affects the scanning time, but pinhole size does not affect MTF. However, in real experimental setup shorter wavelengths are limited by SNR. In practice, it is necessary to use more powerful sources with a wide spectrum. Also SNR is decreased by decreasing pinhole size. There is an optimal balance between scanning time and quality of image reconstruction. Scanning time is determined by the pinhole size, which is determined by necessary spatial resolution of the object and the SNR. The quality of image reconstruction depends on the wavelength of used THz radiation which is determined by the width of its spectrum.

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