Terahertz imaging and holography with a high-power free electron laser

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Abstract

In this paper we describe the terahertz imagers which characteristics are adequate for measurement of high power terahertz radiation. Three imaging techniques were employed on the Novosibirsk terahertz free electron laser (NFEL): near-infrared thermograph, thermosensitive visible light interferometer, and "a thermal image plate". All this methods are widely used in experiments with NFEL radiation. As examples, we present here the measurements of laser beam coherence and describe experiments on terahertz holography.

Characteristics of terahertz imagers

Radiation of the Novosibirsk terahertz free electron laser [1] is emerged as a continuous train of 40–100 ps pulses with the repetition rate of 2.8 – 11.2 MHz. Maximum average power reaches P_{ave} = 400 W at f = 11.2 MHz. The experiments described below were carried out at f = 5.6 MHz and P_{ave} = 50 – 100 W.

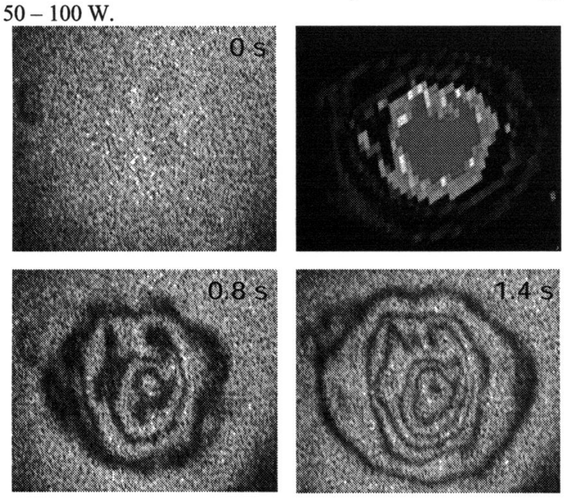

Fig. 1: Cross-section of the terahertz beam at the beamline output recorded with NIT (right upper picture) and with TSI. Figures on the interferograms denote the time after the shutter opening.

Operational principles of two imagers were described in [2]. As a convenient routine imaging instrument we use a 128x128 pixel InAs NIR thermograph (NIT) coupled with the screens non-transparent for both submillimeter and 2.5 – 3 μm radiation. Other technique, developed for THz imaging, was a thermosensitive visible light interferometer (TSI). Red semiconductor laser radiation reflects from two surfaces of a plane-parallel glass plate. Reflected beams interfere on a white screen. When terahertz radiation exposes to one of the plate surfaces, the fringe pattern (Fig. 1) appears because of the thermooptical effect. Terahertz intensity distribution can be then retrieved by standard digital methods. The thermosensitive interferometer is an "absolute" instrument because

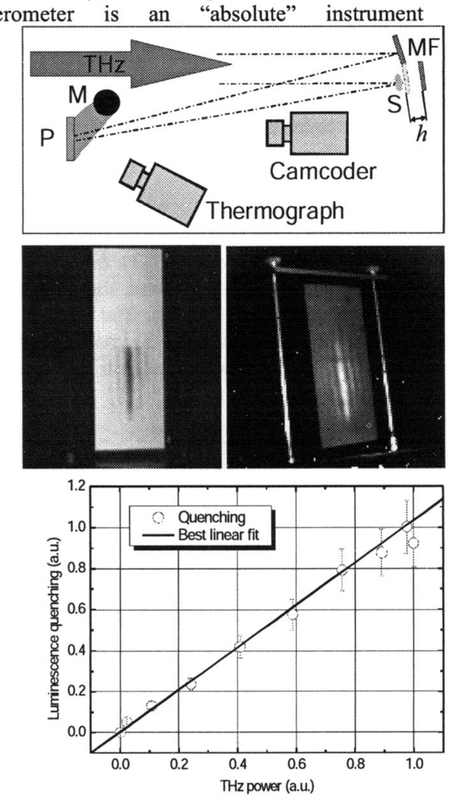

Fig. 2: Experimental configuration for calibration of the thermal image plate and for the experiments on coherence study and recording of holograms (M – mercury lamp, P – a plate with phosphor surfaces #7 (upper half-plate) and #8, MF – Fresnel bi-mirror, S – position of an object in the holography experiments). Left image – fluorescence quenching recorded with the camcoder, right image simultaneously taken with the thermograph. The plot is the response of the surface #8 vs. terahertz radiation intensity.

the thermooptical constants for the materials of interest are tabulated, and calculation of the absolute areal energy deposition can be easy done. One interference fringe in Fig. 1 corresponds to the absorbed energy of 5.4 J/cm^2. One can see that the images obtained with NIT and TSI are similar. Space resolution of TSI is rather good and it enables detection of a fine wavefront structure. It has to be emphasized that simultaneous recording of an image with these two imagers enables to resolve ambiguity inherent to interferogram reconstruction.

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We have adopted for imaging of terahertz radiation a system based on thermal quenching of phosphor fluorescence. A Macken Instruments Thermal Imaging Plate (TIP), Model 22-B, surface #8, was exposed (Fig. 2) simultaneously to radiation of UV mercury lamp and to terahertz radiation. Luminescence intensity was recorded with a digital video camera, whereas temperature distribution over the plate surface was simultaneously recorded with the thermograph. The fringe pattern imaged with TPI is obtained by refection of the terahertz laser beam from the bi-mirror at h = 0 mm. Using a wire polarizer, we gradually attenuated laser beam power to calibrate the TIP response. It was found (see the plot in Fig. 2) that the response of the system TPI+camcoder is practically linear at least up to 60% quenching. This is a very surprising result because the dependence of quenching on temperature in general case is not linear: The thermograph detected at that time the surface temperature growing to 38 C, while the initial phosphor temperature without terahertz beam was 26 C (1.5 C higher then the environment). High spatial resolution of TIP coupled with a camcoder enables recording of precise terahertz images in real time.

Study of space and time coherence of free electron laser radiation with THz imagers

The interference patterns recorded by TPI for the Fresnel bi-mirror configuration gave evidence that the laser radiation possess complete transverse coherence. The images recorded for several mirror displacements (Fig. 3) enable estimation of the time coherence $\tau = 2h_c/c$, which appears to be about 50 ps.

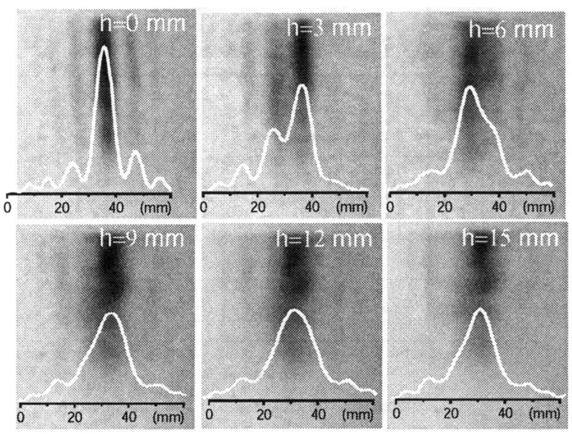

Fig. 3: (a) Interference patterns recorded by TIP for the terahertz beam reflected from the bi-mirror; *h* is a longitudinal displacement of one of the mirrors.

These and other results obtained with TIP demonstrate great capability of the technique based on thermal quenching phosphor fluorescence for terahertz imaging.

Holography in the terahertz spectral region

Using the TIP imager, we continue our experiments [2] on the terahertz holography. The interferogram shown in Fig. 4, *a* is already a simplest on-axis Gabor hologram. Using standard methods of digital holograpy (see e. g. [3]) we easy reconstructed image of the opening. More complex holographic experiment is shown in Fig. 6, *b, c, d.* In this case we simply used the bi-mirror scheme that is, obviously, not optimal for such experiments, because doubled distance between the statuette and the mirror is more than the coherence length. Though only the shadow of the statuette can be retrieved for such configuration, feasibility of high resolution terahertz holography with TIP imager has been clearly demonstrated.

The hologram in Fig. 3, *e* was recorded when the right mirror had been covered with a mask from porous nickel foil with a Γ-shaped opening. The foil scatters terahertz radiation and the mirror reflects terahertz radiation through the opening. In the reconstructed image (Fig. 3, *f*) one can more or less clear see an image of "Γ".

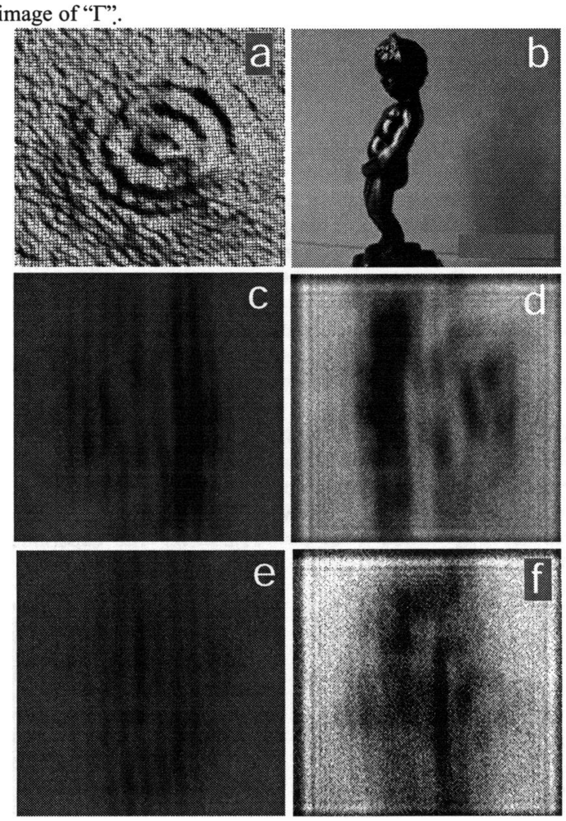

Fig. 4: Holography with the THz laser beam (λ = 128 μm): (a) 3D-plot of the on-axes hologram formed of the beam reflected by a spherical mirror with 4.5-mm opening; (b) a statuette posted in front of one of the mirrors (see Fig. 2); (c, d) hologram of the statuette and its reconstruction; (e, f) hologram of a Γ-shaped mask attached to one of the mirrors and its reconstruction. When there is no any object inside the terahertz beam, "hologram" looks like parallel fringes.

Acknowledgments

This work was supported in part under grant 174/03 from Siberian Branch of Russian Academy of Science.

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