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Real-time speckle metrology using terahertz free electron laser radiation

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ABSTRACT

Real-time speckle photography in the terahertz spectral region was experimentally demonstrated using a 160×120 microbolometer focal plane array (FPA). Novosibirsk free electron laser was employed as a source of 2.3 THz monochromatic coherent radiation. A speckled image of an object which was illuminated by radiation diffusely reflected from a rotating scatterer was projected on the FPA. Two hundred fifty frames of the terahertz "video" recorded by the FPA with a repetition rate of 41 frames/s were used for reconstruction of the amplitude, period, and logarithmic decrement of damped rotational oscillations of the scatterer.

1. Introduction

Mechanics and modern material science show increasing interest in contactless and non-destructive material testing. Speckle correlation technique, also known as speckle metrology, is extensively used for non-contact determination of deformation and movement of a diffusely reflecting object [1]. Speckle metrology can be classified into two groups: speckle photography, involving incoherent recording of two speckle fields and speckle interferometry, when a reference beam is employed. Speckle photography makes use of a random collection of bright and dark speckles formed in space, when a diffuse surface is illuminated with a coherent light. It essentially consists of recording and analyzing the positional shift of speckles generated before and after deformation or movement of the object. The resulted speckle correlation fringe patterns reveal information pertaining to the movement and distortion of the object.

Up to now, speckle metrology was employed only using coherent radiation in the optical spectral range. In this paper we demonstrate the feasibility of speckle metrology in the terahertz range. Two technical achievements were crucial for the development of real-time terahertz speckle metrology. On the one hand, the recently commissioned high-power free electron laser [2] enables object illumination with monochromatic coherent terahertz radiation. On the other hand, a microbolometer focal plane array (FPA) sensitive to terahertz radiation enables real-time recording of terahertz images [3]. In this paper we demonstrate the application of real-time speckle photography for detection of in-plane movement of an object.

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2. Experimental setup

The experimental setup was extremely simple (Fig. 1). A low-divergence parallel beam of Novosibirsk free electron laser (NovoFEL) illuminated a rough copper foil attached to a rotatable disk ("scatterer"). In the reference experiments the scatterer can be replaced with a plane mirror. The radiation can be continuously tuned within the spectral range of 1.2–2.4 THz. In these experiments the radiation frequency was equal to 2.3 THz (λ=130 μm). The radiation scattered by the foil illuminated an object. The lens imaged the object with demagnification onto a 160×120 microbolometer FPA operating at a high repetition rate. Since the laser emitted the radiation as a continuous stream of 100-ps pulses with a repetition rate of 5.6 MHz, the radiation can be assumed to be a steady state for the FPA, the response time of which is about 10 ms [4].

Speckled images of objects illuminated with diffuse terahertz radiation were observed using a very similar experimental setup [2]. A study of the first- and second-order statistics of the terahertz speckle structure showed [5] that it obeyed the same regularities as speckles in the visible region [6]. This first observation of terahertz speckle patterns in the space domain opened the door to speckle photography and speckle interferometry in the terahertz spectral range.

3. Experimental results

In these experiments we used a stationary plane metallic key (see Fig. 1) as an object. A terahertz video was recorded for both static and rotating scatterer. If the rotation speed was substantially high, a reasonable quality image of the key was seen because of overlapping of many incoherent speckle patterns during the

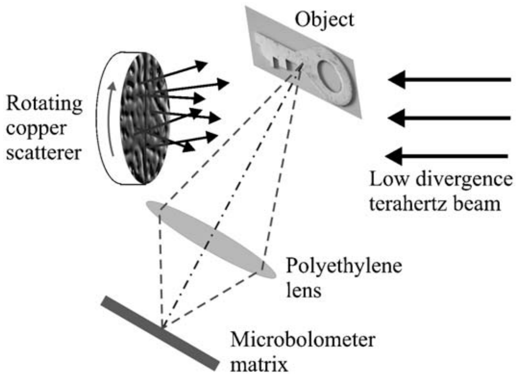

Fig. 1. Experimental setup.

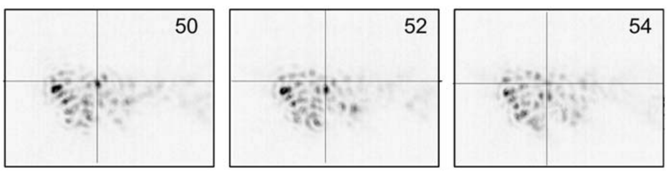

Fig. 2. Three frames extracted from the "terahertz video" (41 frames/s): inverted images of a stationary metal key illuminated with diffuse radiation reflected from a rotating scatterer.

frame exposure. In case of a slow rotating scatterer, individual speckle patterns were recorded in each frame (Fig. 2). The speckle pattern structure stayed similar during several sequential frames.

To demonstrate the feasibility of terahertz speckle metrology, we recorded a terahertz video with a rotating scatterer spinning down. Tracing the speckle pattern moving over the object image, we measured the scatterer displacement "manually", frame-by-frame. The result of this procedure for 250 sequential frames is presented in Fig. 3. All individual measurements were done with observation of the displacement of speckles passing nearby the brightest speckle seen in Fig. 2. The solid curve obtained by fitting the experimental points with the function $y=y_0+A\exp(-t/T)\sin[\pi(t-t_c)/w]$ enabled high precision (Adj. *R*-Square is equal to 0.993) determination of the amplitude (see the vertical axis in Fig. 3), period (w=1.9 s), and logarithmic decrement (T=2.9 s) of damped rotational oscillations of the scatterer.

4. Conclusion

Results of this work have clearly demonstrated the feasibility of speckle photography using monochromatic terahertz radiation and a fast recorder sensitive to terahertz radiation. With the technique of the second-order Pearson correlation function for sequential pairs of frames (see Fig. 2 and paper [5]), data can be processed digitally, which enables real-time speckle photography

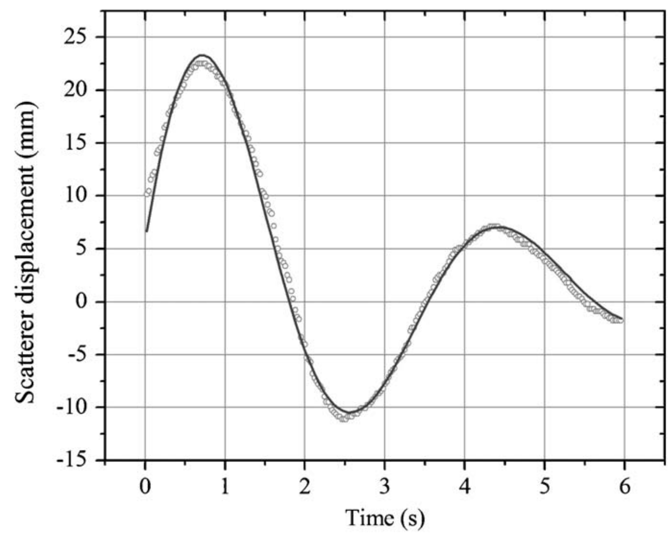

Fig. 3. Amplitude of damped oscillations of a rotating scatterer (points at a radius of 4 cm) retrieved from sequential frames of the speckle pattern.

in the terahertz spectral region. Obviously, complete transverse spatial coherence and a 3-cm coherence length, corresponding to the micropulse radiation length, of Novosibirsk free electron laser enables realization of the terahertz speckle interferometry.

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