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On the possibility of controlling the wave front of a wide-aperture HF(DF) laser by the method of Talbot interferometry

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***Abstract*. The possibility of using the method of Talbot interferometry to control the wave fronts of wide-aperture pulsed HF(DF) lasers is studied experimentally. A search for sensitive screens for visualisation of radiation from a HF(DF) laser and other IR lasers is performed. Screens based on fine graphite powder on a rigid substrate proved to be most convenient for recording Talbot interferograms (talbotgrams). The emission of screens excited by laser pulses was detected with a digital photographic camera and images were processed in a PC. High-contrast talbotgrams of multi-frequency radiation of a HF laser were obtained, demonstrating the possibility of controlling the wave fronts of HF(DF) lasers by the method of Talbot interferometry without separating an individual laser line.**

Keywords: *HF(DF) laser, wave-front control, Talbot interferometry, visualisation of mid-IR laser radiation.*

1. Introduction

Electrochemical nonchain HF(DF) lasers are high-power and convenient mid-IR radiation sources (HF and DF lasers emit in the 2.6 – 3.1-μm and 3.6 – 4.2-μm spectral ranges, respectively). The DF laser radiation falls within the atmosphere transparency window. Due to a large number of DF laser lines in this spectral range, this provides unique possibilities for application of these lasers for remote lidar control of atmospheric contaminations [1]. Nonchain chemical lasers are ecologically safe, the initial components of gas working mixtures (SF_6, H_2, D_2, hydrocarbons, deuterocarbons) are nontoxic and inexplosive. Due to their high output energy and pulsed power (~ 400 J and ~ 2 GW [2]), these lasers can be used for measuring concentrations of various substances over long ranges in the atmosphere [3]. At present HF(DF) airborne (helicopter) lidars based on the method of differential absorption, which can be used for remote measurements with the help of a topographic reflector at distances up to 15 km, are being developed [4 – 6]. To form the spatial radiation intensity distribution of high-power HF(DF) lasers by the methods of adaptive optics [7], it is necessary to control the wave-front (WF) shape.

Among a variety of methods for WF optical control (see papers [8 – 10] and references therein), the Talbot interferometry [10] with the optical scheme similar to that of the shadow Hartmann method [8] seems to be attractive for measuring the WF shape for wide-aperture high-power lasers. A distinct feature of the Talbot interferometry is the possibility to study the WF shape by a Talbot interferogram (talbotgram) – the contrast distribution of the coherent radiation intensity formed by a two-dimensional grating with identical periodically arranged holes. Unlike a hartmanngram, a talbotgram serves as an indicator of the field coherence over the entire WF aperture. The distortion of the WF shape is calculated from the displacement of contrast light spots coinciding in shape with holes. Upon measurements of displacements of light spots, the requirements to the photometry of the radiation intensity distribution in talbotgrams are less stringent than in the case of hartmanngrams, while the sensitivity to phase distortions and spatial resolution of a Talbot WF sensor is higher than that of a Hartmann sensor [10].

High-contrast talbotgrams are usually obtained by transmitting monochromatic radiation through a two-dimensional grating [10]. The spectrum of each radiation pulse from a HF(DF) laser contains many lines, and the aim of this paper is to study the possibility of using Talbot interferometry for recording the WF shape of such lasers without separating an individual laser line.

2. Experimental

2.1 Control of the WF shape by the method of Talbot interferometry

The method of Talbot interferometry and its applications for WF analysis of wide-aperture laser beams is discussed in detail in [10] (where a review of other methods for WF analysis is also presented).

Plane waves in the method of Talbot interferometry are decomposed in a two-dimensional grating with identical periodically arranged holes of arbitrary shape into spatial harmonics propagating at multiple angles, which interfere to reproduce the intensity distribution on the grating at distances

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$$L_n = \frac{2p^2 n}{\lambda} \quad (1)$$

in the near Fresnel zone, where L_n is the distance from the grating to the reproduction plane; p is the grating period; λ is the radiation wavelength; $p \gg \lambda$; and $n = 1, 2, 3 \ldots$.

The intensity distribution in reproduction planes in the case of the plane or spherical WF has a periodic structure similar to the grating. In the case of the plane WF, the distribution periods coincide with these of the grating. In the case of the convex or concave WFs, the distribution periods increase or decrease, respectively. If the WF is not plane or spherical, the periodicity of the intensity distribution in the reproduction plane is distorted. An increase in the period in some region of the beam aperture indicates that an optical inhomogeneity of the scattering lens type appears in this region, while a decrease in the period indicates that a focusing lens appears.

Unlike intensity distributions in hartmanngrams, light spots of talbotgrams on a receiving screen have a high contrast because the width of spot boundaries is determined by the WF diffraction not from a single hole, as in the Hartmann method, but from the grating aperture. The operation of the WF sensor is based on the measurement of the displacement of coordinates of contrast light spots in talbotgrams distorted by the WF in reproduction planes. Local WF inclination angles $\Delta\gamma$ are measured in reproduction planes. In the optical wedge approximation, we have $\Delta\gamma = \Delta r / L_n$, where $\Delta r = [(\Delta x)^2 + (\Delta y)^2]^{1/2}$ and Δx, and Δy are the displacements of spot coordinates due to WF distortion (in the rectangular coordinate system). The normal WF deviation is $\Delta z = p\Delta\gamma$. The radius of WF curvature is determined in the parabolic approximation by a change Δp in periods in the reproduction plane: $R = pL_n/\Delta p$. To obtain information on the WF shape, it is sufficient to measure coordinates of the centres of contrast radiation spots in talbotgrams.

2.2 Choice of screens for visualisation of radiation of a nonchain HF(DF) laser

The main criterion for the choice of a material for screens was the possibility of obtaining a processable interferogram in an unfocused laser beam after its propagation through a periodic grating. According to this requirement, screens should have a rather high sensitivity to laser radiation. We studied screens based on a thermosensitive paper and a metallised polyethylene film and screens based on paper or a vinipros film covered with fine graphite powder (graphitised screens). Interferograms on screens of the first two types, obtained due to the destruction of coating by laser radiation, were scanned and fed into a PC for further processing. The emission of graphitised screens excited by laser radiation was photographed with a digital camera and the image was also fed into a PC for processing.

2.3 Scheme of the experiment on recording talbotgrams

We used in experiments a TH-15 nonchain electrochemical HF(DF) laser with the discharge volume ~ 3 L developed at the General Physics Institute, RAS. The output energy of the HF and DF lasers were 15 and 12 J, respectively. Lasers emitted single ~ 140-ns pulses, the time between two successive pulses being no less than 3 min. The working SF_6 mixture with hydrogen or deuterium donors was prepared directly in the discharge chamber. The volume chamber-to-discharge ratio was ~ 80, which allowed us to perform up to 50 shots without changing the working mixture. The chamber was sealed with BaF_2 windows. The external cavity of length 1.8 m was formed by plane aluminium and dielectric mirrors, the reflectance of the output dielectric mirror being 30 % in the spectral range from 2.7 to 3.1 μm. The radiation divergence was reduced and the quality of the laser beam in the discharge chamber was improved by using two circular apertures of diameter 5 cm, which transmitted the central part of the laser beam. In this case, the maximum output energy of the HF laser was 3.5 J. No spectral selection of radiation was performed. It is known that the HF laser emits in this regime more than 15 spectral lines [11].

Figure 1 shows the general scheme of experiments on the visualisation of talbotgrams at the emission wavelengths of a nonchain HF(DF) laser by using various screens. The laser beam passes through a periodic grating (of thickness 0.1 mm with period $p = 1$ mm) and is incident on the surface of a screen mounted at a distance $L_n = 2np^2/\lambda$ from the grating (plane WF). The HF laser was used in most of the experiments, and $n = 1$. The value of L_1 was varied from 65 to 77 cm. For the most intense laser line at 2.7 μm, the distance L_1 was 74 cm. The image on the surface of graphitised screens emitting in the visible spectral region upon excitation by laser pulses was recorded with a digital camera. Figure 1 shows that photography was performed either at an angle to the optical axis (opaque screen) or from the opposite side of a semitransparent vinipros film screen.

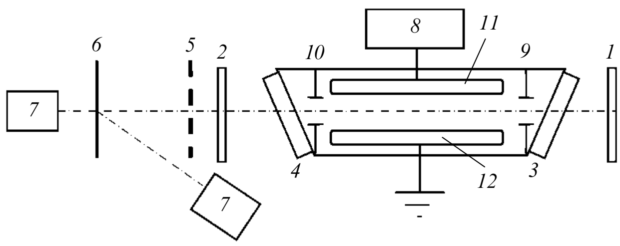


Figure 1. Scheme of the experiment: (*1*, *2*) HF(DF) laser mirrors; (*3*, *4*) BaF_2 plates; (*5*) periodic grating; (*6*) screen; (*7*) digital photographic camera; (*8*) pulse voltage generator; (*9*, *10*) 5-cm circular apertures; (*11*, *12*) laser electrodes.

The laser energy density W on the periodic grating surface was varied from 0.1 to 0.3 J cm^{-2} depending on the screen sensitivity.

3. Experimental results

The sensitivity of thermopaper screens to unfocused laser radiation proved to be insufficient for recording the interference pattern. The use of a metallised film screen provided the recording of high-contrast talbotgrams. In this case, talbotgrams could be reliably recorded when the laser energy density W on the grating surface exceeded 0.18 J cm^{-2}. Figure 2 presents the image of the imprint of the laser beam on a metallised film screen placed at a distance of $L_1 = 74$ cm from the grating. One can see from this figure that, despite a great number of lines in the emission spectrum of the laser, the image has a high

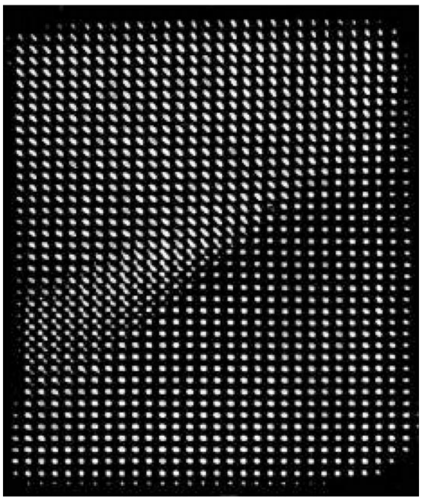
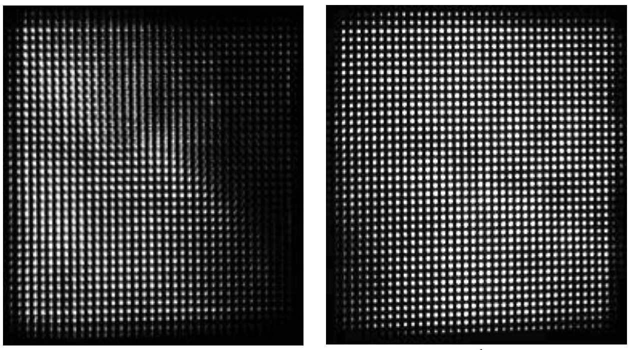


Figure 2. Talbotgram image obtained by scanning on a metallised film for $L_1 = 74$ cm.

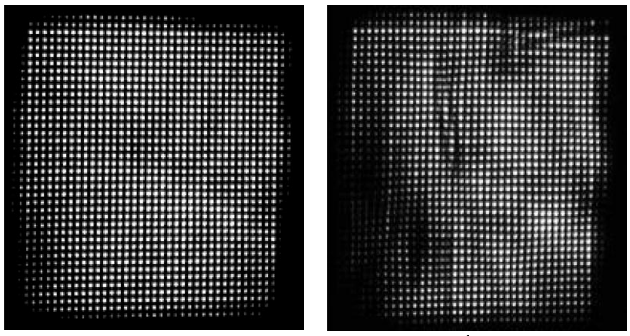
contrast, which allows us to determine the coordinates of spot centres in the talbotgram and to construct a two-dimensional pattern of the laser beam WF. However, a disadvantage of the metallised film screen is a rather high destruction threshold of the metal layer and the 'expendable' usage.

Graphitised screens proved to be more convenient. Their emission could be reliably recorded with a digital camera when the incident energy density was $W \approx 0.12$ J cm^{-2}. Figure 3 shows interferograms obtained on a paper screen coated with graphite powder, for $L_1 = 74$ cm. They demonstrate the influence of the cavity alignment of the radiation WF (the cavity is misaligned and aligned in Figs 3a and 3b, respectively). One can see from Fig. 3a that the cavity misalignment leads to the 'smearing' of the interference pattern. If the cavity mirrors are properly aligned, the interferogram becomes bright and highly contrast. Figure 4 shows interferograms obtained on the same screen for the same $L_1 = 74$ cm. They illustrate the influence of the atmospheric perturbations of the laser radiation WF (in Fig. 4a, the atmosphere in the laser beam path is not perturbed, while in Fig. 4b the atmosphere is perturbed by a thermal flow from the flame of a candle placed behind the output mirror at a distance of ~ 1 m from the periodic grating and 20 cm below the optical axis of the system). One can see from Fig. 4b that the thermal flow noticeably distorts the WF.



a b

Figure 3. Talbotgrams obtained on a paper screen coated with graphite powder for the misaligned (a) and aligned (b) laser cavity; $L_1 = 74$ cm.



a b

Figure 4. Talbotgrams obtained on a paper screen coated with graphite powder when the atmosphere in the laser beam path was unperturbed (a) and perturbed by a thermal flow (b); $L_1 = 74$ cm.

Vinipros film screens coated with graphite power proved to be preferable for visualisation of interferograms. Because these screens are transparent in the visible spectral range, the emission of graphite excited by laser radiation could be recorded with a digital camera mounted behind the screen on the optical axis of the system (Fig. 1), which excluded the distortions of the pattern caused by the photography angle in the case of opaque screens. Figure 5 shows the talbotgram obtained for the distance between the semitransparent screen and periodic grating equal to $L_2 = 148$ cm. By comparing Figs 3, 4, and 5, we see that the increase in n reduces the area of the contrast interference pattern. In the interferogram the extreme rows of bright spots disappear, i.e. the information content about the WF decreases as a whole. Therefore, it is reasonable to record talbotgrams for $n = 1$. Note that talbotgrams had a high contrast over the entire emission range of the HF laser. Undoubtedly, this interferometric method can be also used to control WFs of DF lasers.

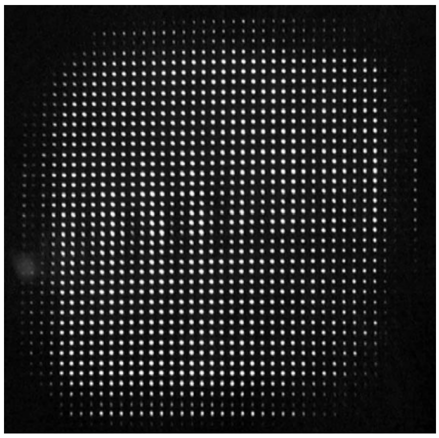


Figure 5. Talbotgram obtained on a semitransparent graphite screen for $L_2 = 148$ cm.

4. Conclusions

We have shown the possibility of using the method of Talbot interferometry to control WFs of wide-aperture pulsed HF(DF) lasers. Different screens for visualisation of interferograms have been studied. The most convenient for this purpose are graphitised screens (paper and vinipros film coated with graphite powder), which have a high sensitivity to laser radiation. The use of such screens and modern digital photographic cameras provides a rapid introduction of recorded interferograms into a PC for further processing. An advantage of graphitised screens is also the absence of aperture restrictions, which permits their use for controlling WFs of high-power wide-aperture HF(DF) lasers and other IR lasers.

Note that the HF(DF) laser beam used in experiments had a high quality, which is confirmed by the possibility of obtaining contrast and undistorted talbotgrams at distances L_2 corresponding to the second reproduction plane.

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