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Femtosecond recording of holograms and hologram-like structures in volume recording media*

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***Abstract*. Reflection holograms in thick layers of bichromated gelatin are recorded by using 50-fs pulses of the second harmonic of a Ti:sapphire laser.**

Keywords: *femtosecond pulses, volume holograms.*

Achromatic reconstruction of the wave front was first reported in Refs [1 – 3]. This effect is associated with the geometro-optical reflection of the reconstructing radiation from the surfaces of constant phase difference between the object and reference waves recorded in the bulk of the medium [4]. The constant phase difference surfaces were recorded by counterpropagating femtosecond laser radiation pulses [5]. In this case, the geometro-optical reflection mechanism dominates over the mechanism of diffraction of radiation from a periodic interference structure owing to a small number of periods registered in the latter case caused by short pulse duration.

As a recording medium, exceptionally thick layers (up to 300 μm) of silver halide materials specially prepared at the Russian Research Center 'Kurchatov Institute' were used in Refs [1 – 3, 5]. Considerable difficulties were encountered during the photochemical processing of these layers due to the fact that a uniform developing over the entire thickness of the photosensitive layer is virtually impossible for such thicknesses. Moreover, the problem of the film thickness variation (shrinkage) caused by photochemical processing was also not solved satisfactorily. Under the actual experimental conditions, even a weak shrinkage led to a distortion of the shape of the reconstructed wave front. Scattering of light in the layer was also unacceptably large. In view of these circumstances, we explore in this work the possibility of femtosecond recording of hologram-like structures in materials that do not contain silver.

Very thick (80 – 120 μm) layers of bichromated gelatin were used as the recording material in our experiments. To prevent flaking of the sensitive layer, which is usually observed for such film thicknesses, the substrate was coated with a special adhesive material. The post-exposure processing included soaking of the sensitive layers in cold water and drawing them through the solutions of isopropyl alcohol with increasing concentration. Two drying techniques were employed – immersion in boiling isopropyl alcohol and air-drying in a centrifuge. In the latter case, the surface of the dried plates was protected by a cover glass using epoxy ED-5 resin with a preliminarily dehydrated hardener (polyethylene polyamide) as the immersion material. The plates were heated after hardening of the resin, which led to further shrinkage. As a result, the thickness of the dried layers was restored nearly to the initial value, thus enabling us to use the same wavelength for reconstructing the image as for recording it.

The hologram was recorded on a setup with a generator of high-power femtosecond pulses based on a $Ti^{3+}:Al_2O_3$ crystal pumped by a solid state cw diode-pumped Millenia V $Nd^{3+}:YVO_4$ laser. The solid state pumping laser had an output power of 5W in the TEM_{00} mode, a wavelength of 532 nm, an instability no worse than 1 %, and the radiation divergence not exceeding 0.5 mrad. The measured spectral width of the generator pulses and the width of the autocorrelation function matching well with it corresponded to a pulse duration of 50 fs, which gives an energy of 5 nJ per pulse for an average output power of 250 mW.

The exposure was performed by the 410-nm second harmonic from a femtosecond pulse laser. The second harmonic was obtained with the help of LBO, BBO and lithium iodate crystals. The crystals had a thickness of 0.5 – 1 mm and the maximum conversion coefficient was 10 %.

The hologram-like structures were recorded using a counterpropagating laser pulses that intersected inside the recording medium. A similar recording scheme was used in Ref. [5]. The technique described in Ref. [5] was used for equalising the optical paths of the pulses. In addition, a new and more convenient technique based on the emergence of a feedback between the recording system and the laser was also proposed. The feedback appears after tuning the recording circuit for an exact equality of the optical paths. In this case, the spectrum of the generated pulse, which is observed continuously on the computer monitor, is considerably distorted . Such a technique makes it possible to equalise the optical paths to within 10 μm. During record-

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ing, the normal to the photographic plate formed an angle of 7° with the optical axis. In all, 24 bichromated gelatin photographic plates were exposed (with 20 holograms on each plate). The exposure dose was varied in the range from 1 to 100 mJ cm^{-2}.

Various sources, including a spectrophotometer lamp, an argon laser (474, 488, 496.5 and 501.7-nm lines) and a Ti:sapphire laser, were used for the hologram reconstruction. In the latter case, the radiation wavelength was varied continuously within a small interval near the second harmonic frequency to verify the existence of the achromatic image.

The processed plates of bichromated gelatin revealed a high luminance when inspected in white light. During the reconstruction by the second harmonic laser pulses from a $Ti^{3+}:Al_2O_3$ laser, the plate was first mounted perpendicular to the laser beam. Two weak reflections on either side of the normal to the plate were observed in the horizontal plane at angles +16 and −16° (the +1 and −1 diffraction orders on the surface hologram). These reflections were displaced upon a rotation of the plate around the vertical axis, their luminance remaining unchanged. When the laser wavelength was changed from 411 to 421 nm, the images at a distance of 2m from the hologram were displaced by 1 cm.

The Bragg image at the recording wavelength was observed as follows. When the plate was inclined to the optical axis at an angle of 60°, a strong reflection diffraction was observed. The image had an angular selectivity of 20°. The spectral selectivity, measured on a spectrophotometer, was ~ 25 nm. The noise during the reconstruction was much lower than in silver halide materials [1–3]. Thus, reflection holograms with weak light scattering in the processed layers were observed in thick layers of dichromated gelatin.

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