LATVIAN JOURNAL OF PHYSICS AND TECHNICAL SCIENCES
2009, N 4
10.2478/v10047-009-0014-1

5th International Student Conference „Developments in Optics and Communications", 2009

PHOTOINDUCED MASS TRANSPORT IN LIQUIDS

V. Duboviks, J. Teteris

Institute of Solid State Physics, University of Latvia,
8 Kengaraga Str., Riga, LV-1063, LATVIA
e-mail: v_d@inbox.lv

Optically induced changes in the concentration distribution of Fluorescein and DCM dye solutions were investigated, with their dependences on the laser intensity and optical properties of solvent examined. In the experiments we used a thin solution layer (~70 μm) between two glass plates, which was exposed to CW laser radiation (λ = 523 nm). Under intensive laser illumination a transport of dissolved dye was observed. The distribution of solution concentration was analyzed using a low-intensity CW laser focused beam. The spectroscopy methods were employed to reveal differences between the absorption spectra of the solution before and after exposure. The solution concentration was proved to change around the exposed spot.

Key words: *Mass transport, Gradient force, Fluorescein, DCM.*

1. INTRODUCTION

The possibility to achieve high-intensity force gradients using continuous wave coherent light beams has led to active development of techniques for optical trapping and manipulation of neutral particles by lasers. These techniques are based on the forces of radiation pressure, which arise from the momentum of the light itself [1]. Currently, visible and infrared laser radiation is applied for the manipulation of individual microscopic particles suspended in a fluid solvent [2]. However, it turns out that the radiation pressure is not the only force for the manipulation of particles.

The net force exerted on the particle by a Gaussian profile laser can be decomposed into two terms – the gradient force and the scattering force. The gradient force traps a particle transversely, while the scattering force controls its axial motion [3]. Usually scattering forces are weak, and only in astronomy, with its huge light intensities and distances, the radiation pressure plays a significant role in moving matter. In most of the experiments on the electromagnetically-driven fluid interface instability a very soft near-critical liquid-liquid interface and a sufficiently large beam power are used [4, 5]. Since we do not use near-critical liquid-liquid interfaces and the laser intensity is moderate, in this article we will consider only the gradient forces.

During our experiments we observed a mass transport in liquid solutions, both to the places with lesser and greater light intensities. Since the solutions used in the experiments are absorptive at a given wavelength, the indirect force known as the radiometric force could explain the particle flow to places with lesser light intensities. The radiometric force results from the molecular collisions at a higher rate from the heated side of a particle than from its other side [6]. However, this

does not explain the particle flow to the places with greater light intensities. This could be assigned to dielectrophoretic force – a phenomenon in which force is exerted on a dielectric particle when it is subjected to a non-uniform electric field. Unfortunately, the lack of quantitative data does not allow exact interpretation of the observed processes.

Despite some ambiguity in theory, the experiments show a potential of using liquids in the optical recording technologies. The dynamic optical recording requires the fully reversible photosensitive material lacking any post-processing [7]. In this article it is shown how the photoinduced mass-transport in liquids could be applied to dynamic optical recording.

2. EXPERIMENTAL

The experimental setup shown in Fig. 1 was used for sample exposure to CW laser radiation. The sample was a 70 μm thick layer of test solution between two glass plates. Such a solution layer prevents unwanted convection, so it allowed us to observe changes even some time after exposure. The laser illuminates continuously at wavelength λ = 523 nm, with intensity being adjustable. The optical scheme includes a polarizer, but up to now we could not reveal the influence of light polarization. The solutions under investigation are absorptive at λ = 523 nm, but this wavelength is far from their absorption maximums. This made it possible to avoid high intensity gradient formation along the direction of light propagation.

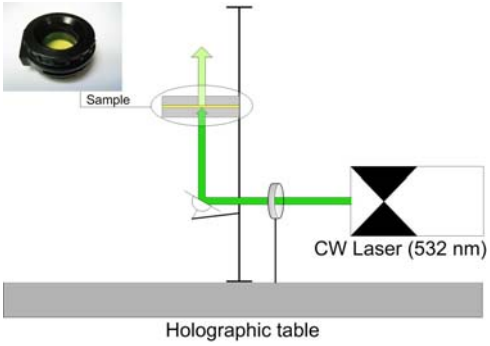

Fig. 1. Experimental setup.

Before and after each exposure we analyzed samples with a spectrometer to observe changes in the absorption curves. We also analyzed the exposed spot with a low-intensity CW laser (λ = 473 nm) focused beam after the exposure. The sample was placed on a shifting-tray, which was moved along one axis. This made it possible to obtain the transmission profile.

3. RESULTS AND DISCUSSION

In Figs. 2, 3 the transmission profiles of samples are shown. These profiles were taken immediately after exposure. Figure 2 corresponds to Fluorescein (2 g/L) aqueous solution with different intensities applied during exposure, while Fig. 3 shows the profile of 4-(dicyanomethylene)-2-methyl-6-(4-(dimethylamino)styryl)-4H-pyran (DCM) isopropanol solution (1g/L). According to the graphs, the

maximum transmittance is at the centre of the exposed spot. With the incident power increasing, the transmission maximum at the centre becomes higher. The laser's beam, to which the sample was exposed, has a Gaussian intensity distribution profile and is 2.25 mm in diameter. From the graphs one can see that the diameter of spot where changes in transmittance took place is around 1cm. This is considerably larger than the beam diameter. Such changes could indicate differences in the solution concentration caused by radiometric force.

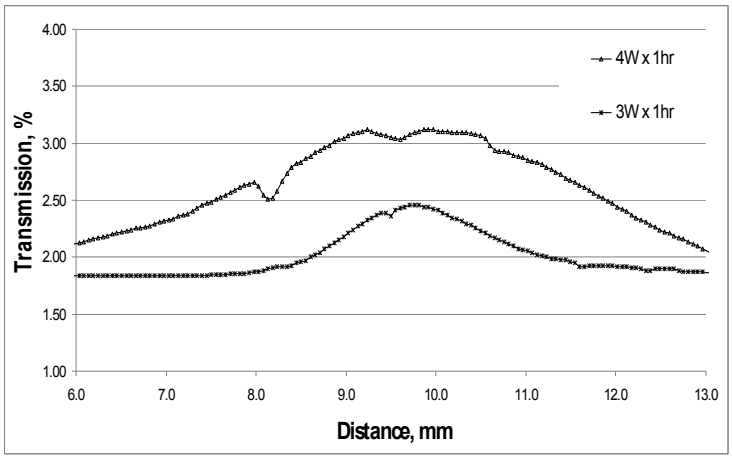

Fig. 2. Transmission profiles of Fluorescein aqueous solution (2 g/L) after 1 h exposure to 4 W and 5 W CW laser radiation (λ = 532 nm). Taken with focused beam of λ = 473 nm laser.

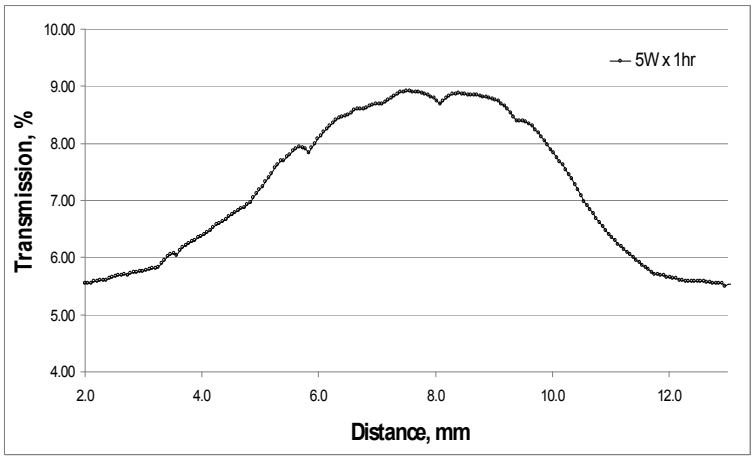

Fig. 3. Transmission profile of DCM isopropanol solution (1 g/L) after 1 h exposure to 5 W CW laser radiation (λ = 532 nm). Taken with focused beam of λ = 473 nm laser.

The measured intensity I transmitted through a layer of material with thickness d is related to the incident intensity I_0 according to the inverse exponential power law:

$$I = I_0 e^{-d\alpha},$$

where α is the attenuation coefficient directly related to concentration.

If the thickness remains unchanged, as it was in our experiments, the changes in transmittance are to be related to changes in solution concentration. This is confirmed by Fig. 4, where the absorption spectra of the sample before and after the exposure are shown. The DCM (1 g/L) isopropanol solution was exposed to a 5 W laser beam for one hour.

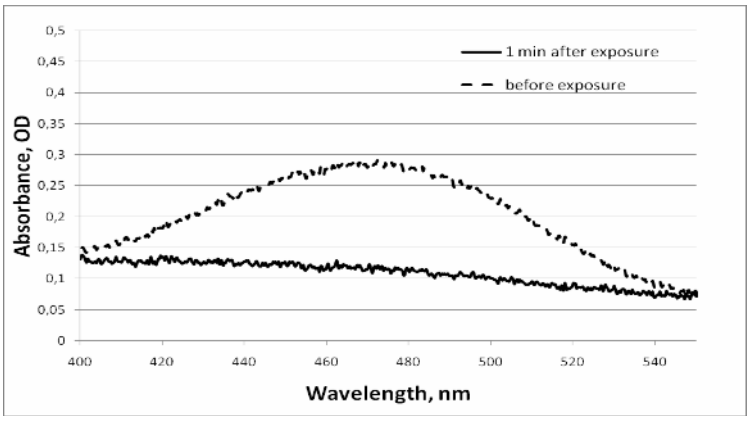

Fig. 4. Absorption spectra of the DCM isopropanol solution (1g/L) before (dashed line) and 1 min after (continuous line) the exposure.

The temperature of liquid rose slightly during the experiment due to light absorption. Usually, when temperature rises gases become less soluble in water but more soluble in organic solvents [8]. Thus, after long expositions or relatively high intensities of the laser, some bubbles formed in aqueous solution. The temperature rise also decreased the viscosity of solution.

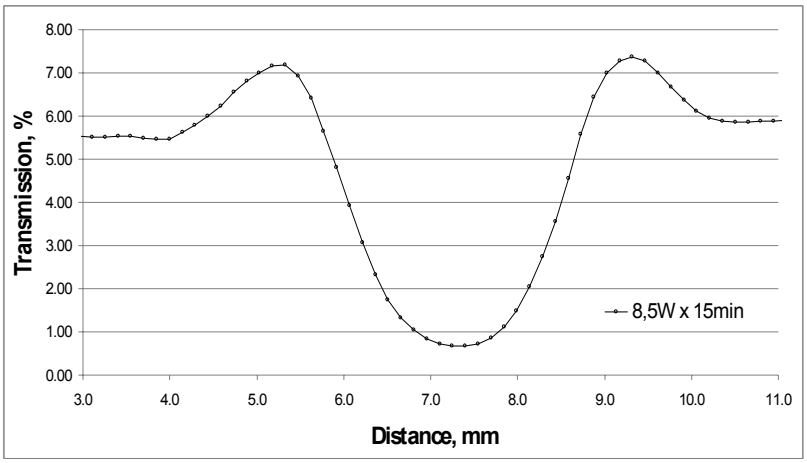

Fig. 5. Transmission profile of Fluorescein aqueous solution (2 g/L) after exposure to 8.5W CW laser radiation (λ = 532 nm). Taken with focused beam of λ = 473 nm laser.

Figure 5 shows the transmission profile of Fluorescein aqueous solution after exposure to 8.5 W. The transmittance at the centre is smaller, and two transmission maximums on the sides appear. On the real sample two side maximums show themselves as a light ring around the dark spot. Shortly after the exposure, absorbance at the centre changes as is shown in Fig. 6. The curve is shifted upwards

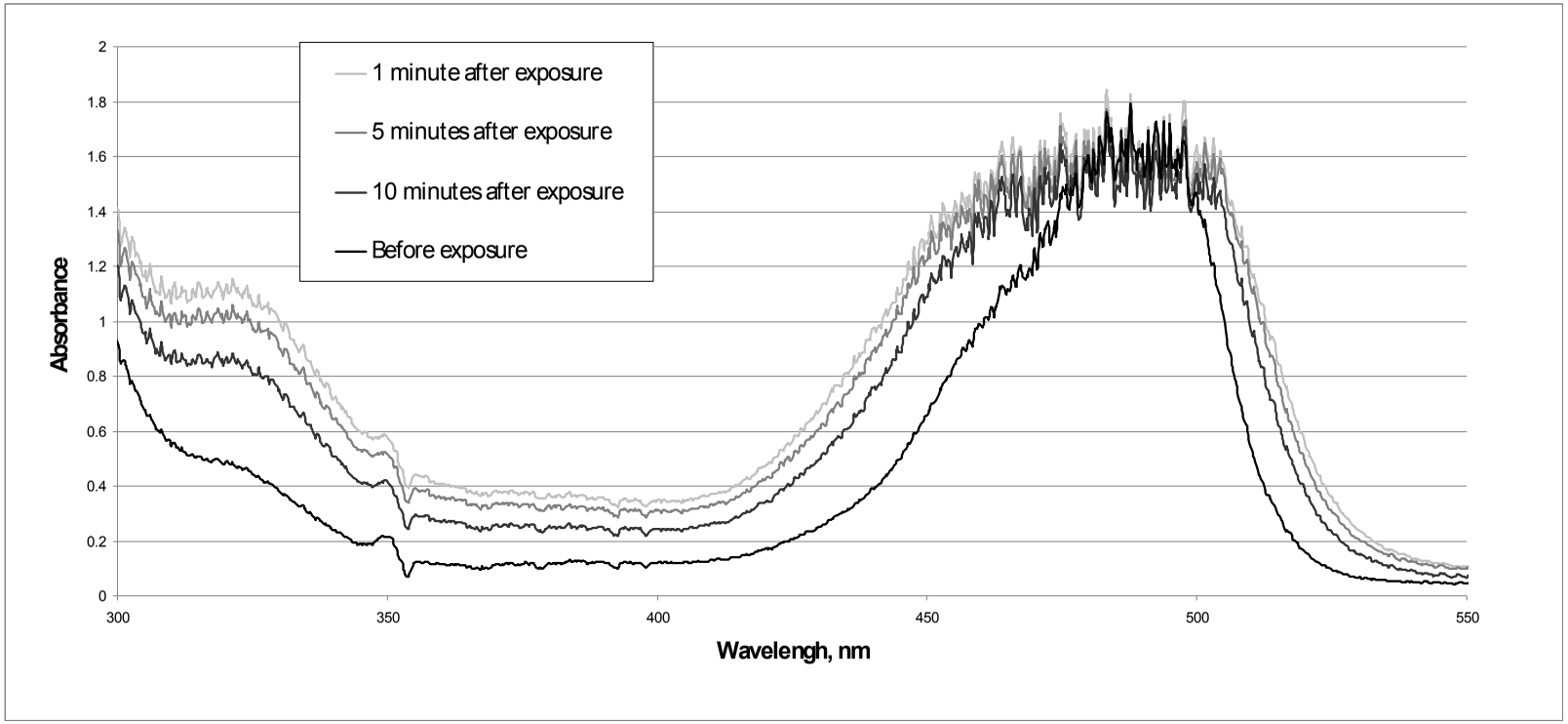

Fig. 6. Absorbtion spectra of Fluorescein aqueous solution (2 g/L) before and 1 min, 5 min, 10 min after exposure.

at all points for approx. the same relative value, except for the location of an absorption maximum. This is explained by the spectrometer's super-saturation.

Since the intensity of holographic recording is variable, changing the concentration of solution with laser light we can record amplitude holograms. Liquids are believed to be suitable in dynamic holography, due to their very low viscosity in comparison with common holographic materials.

4. CONCLUSION

The changes observed in the solution concentration clearly denote the presence of a photoinduced mass transport. It is still not evident what processes are here involved. Two different types of profiles were shown – with transmittance maximum at the centre and with a light ring around the dark spot. We consider that several different mechanisms are responsible for the changes, e.g. dielectrophoresis and thermophoresis. To clarify the nature of these phenomena further investigation is needed.

REFERENCES

1. Ashkin, A. (1997). Optical trapping and manipulation of neutral particles using lasers. *Proc. Natl. Acad. Sci.* (USA), *94*, 4853–4860.
2. Terray, A. (2005). Enhanced optical chromatography in a PDMS microfluidic system. *Optics Express, 13* (25), 10407–10415.
3. Bum Suk Zhao, Yoon-Mo Koo, & Doo Soo Chung (2006). Separations based on the mechanical forces of light. *Analytica Chimica Acta, 556*, 97–103.
4. Casner, A., & Delville, J.P. (2003). Laser-induced hydrodynamic instability of fluid interfaces. *Phys. Rev. Lett., 90* (14), 144503-1–144503-4.
5. Casner, A., Delville, J.P. (2001). Giant Deformations of a Liquid-Liquid Interface Induced by the Optical Radiation Pressure. *Phys. Rev. Lett.,* Vol. 87, No. 5, pp. 054503-1–054503-4.
6. Rohatschek, H. (1999). *History of Photophoresis*. Vienna, Austria, Osterr. Akad. d. Wissenschaften
7. Miniewicz, A. (2006). *Organic materials for dynamic holo*graphy. Proceedings of the Symposium on Photonics Technologies for 7th Framework Program, Wroclaw, Poland, pp. 234–239
8. John W. Hill, Ralph H. Petrucci (1999). *General Chemistry*, 2nd edition, Prentice Hall.

FOTOINDUCĒTA VIELU DIFŪZIJA ŠĶIDRUMOS

V. Duboviks, J. Teteris

K o p s a v i l k u m s

Darbā pētītas fluoresceīna un DCM krāsvielu koncentrācijas sadalījuma fotoinducētas izmaiņas plānā (70 μm) šķīduma slānī. Tika pētīta 532 nm lāzera starojuma intensitātes un šķīdinātāja ietekme uz šķīduma kārtiņas optisko caurlaidību. Novērota slāņa optiskās caurlaidības palielināšanās apgaismotajā zonā un samazināšanās neapgaismotajā slāņa zonā. Fotoinducētās caurlaidības izmaiņu izskaidro ar krāsvielu koncentrācijas izmaiņām, kuras izraisa lāzera starojuma intensitātes gradienta radītie spēki.