Compact laser tweezers

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ABSTRACT

In this article we present laser diode based tool for optical manipulation with microobjects. This tool is very suitable for micromanipulations with large spectrum of speciments in the diameter range 0.5 - 30 μm. Adapter is directly mounted to the microscope without any aditional improvements and fits to many comercially available microscopes. Key feature of this adapter is compactness, usability and simple handling. With this adapter user takes advantage of wide spectrum of comercially available laser diodes with different wavelengths. For this reason the tool can be used in many areas such as biology, medicine and measurements.

Keywords: laser tweezers, laser diode, optical manipulation

1. INTRODUCTION

Optical manipulations with light are very popular techniques in many areas of science.[1–5] Basic tool is based on strongly focused laser beam emanating from many types of laser sources – solid state, gas and semiconductor.[6] For creation of stable, spatially localized optical trap is necessary to obtain high spatial gradient of light intenzity of trapping beam in the vicinity of focal point. In standard instrument for optical manipulations, e. g. optical tweezers, this is done by focusing of laser beam by optical system with high numerical aperture. Classical component suitable for this condition is high-quality microscope objective (water or oil immersion with NA higher than 1). Commonly used are infinity-corrected types, where collimated laser beam enters back focal plane of microscope objective and overfills back aperture. Standard systems use mainly epi-fluorescent port of the light microscope as an entrance for this beam. Lasers emitting in near-infrared part of optical spectra are mostly used for optical trapping of biological objects due to small influence on environment of these objects. However optical parts of microscopes are optimized for working in visible part of spectra. Main problem is coating of optical elements of microscope which is optimized for observing image in visible or in some cases in ultraviolet region of optical spectra.

Compact optical tweezers (COP) presented in this article overcome this problem by inserting light generator straightforward between microscope body and microscope objective. For optical trap generation, the microscope body is not necessary and instrument can work standalone, the microscope body acts only as support. COP does not affect construction of microscope and all features of observing images are well-kept. Presented COP does not need presence of epi-fluorescencent port in the microscope body, it is suitable for creating optical trap in low cost types of microscopes. If ultraviolet laser diode is used as laser light source, COP can by used as a optical scissors[7–10] or for photopolymerization techniques. COP can act as source for excitation of spectral lines with another types of laser diodes.

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2. CONSTRUCTION

We used laser diode (Sanyo DL-8031-031A) as a laser radiation source of emitted light with wavelength 808 nm and base transversal profile TEM_{00}, maximal output power 200 mW. Emanated beam was collimated by aspherical lens with focal length 8 mm (Geltech 352240-B) and eliptical beam profile was corrected by anamorphic prism pair (Thorlabs PS871-B).[11] This improved beam was than retroreflected by pair of mirrors into infinity-corrected microscope objective. The first mirror is coated with multilayer for maximum reflectance for wavelength of laser diode. The second mirror has multilayer with maximum reflectance for laser diode in one direction and maximum transmittance for visible light in opposite direction. This optical system was entered to Zemax optical program (Fig. 1) and optimization was performed. From figures is clearly seen that beam is diffraction limited, e.g. focus is smaller than Airy disk of optical system. Mechanical construction of the COP

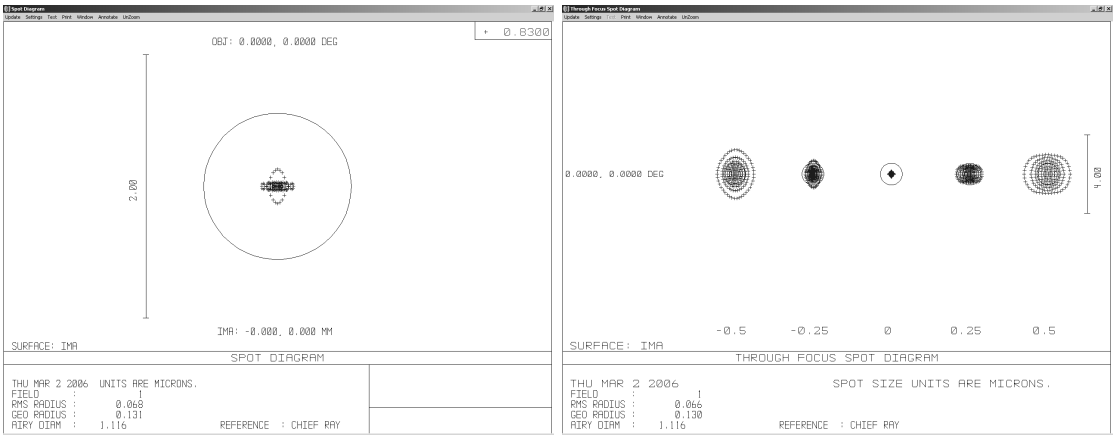

Figure 1. Spot diagram (left), through focus spot diagram (right) from Zemax optical program.

was made in Autodesk Inventor (Fig. 2) with demand of maximal compactness, easy to use, modularity (use more COP's at the same time). Stability of power in the focal point was achieved by temperature stabilization of laser diode by Peltier module (Supercool PE-017-06-11) and appropriate selection of construction materials. Stability of current to the laser diode was done by homemade current controller.[12]

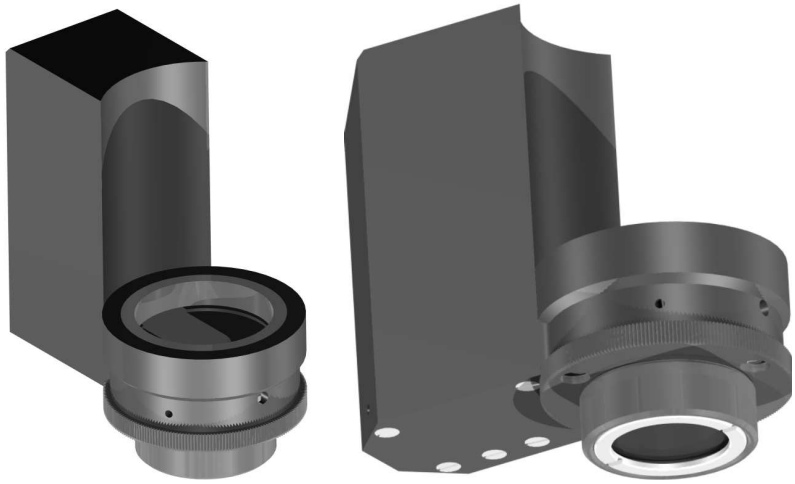

Figure 2. Left and bottom isometric view of compact optical tweezers from Autodesk Inventor.

3. EXPERIMENTS

Trapping power of COP was checked in combination with inverted microscope Olympus IX-70. Microscope objective Olympus Ach 100x was used as a focusing element (see Fig. 3). Three-dimensional manipulations with polymer particles with diferent sizes (Duke Scientific) freely diffused in deionized water were performed. Power in the focal point was kept for inverted microscope at level 55 mW. Images were aquired by b/w CCD camera (Mintron, 63W1C) and digitized by framegrabber card (Picasso PCI-2SQ, Arvoo). Position of the image plane is changed by lateral movement of microscope stage and longitudinal movement of microscope objective. Image of trapped particle is still focused (see Figs. 4, 5, 6, 7).

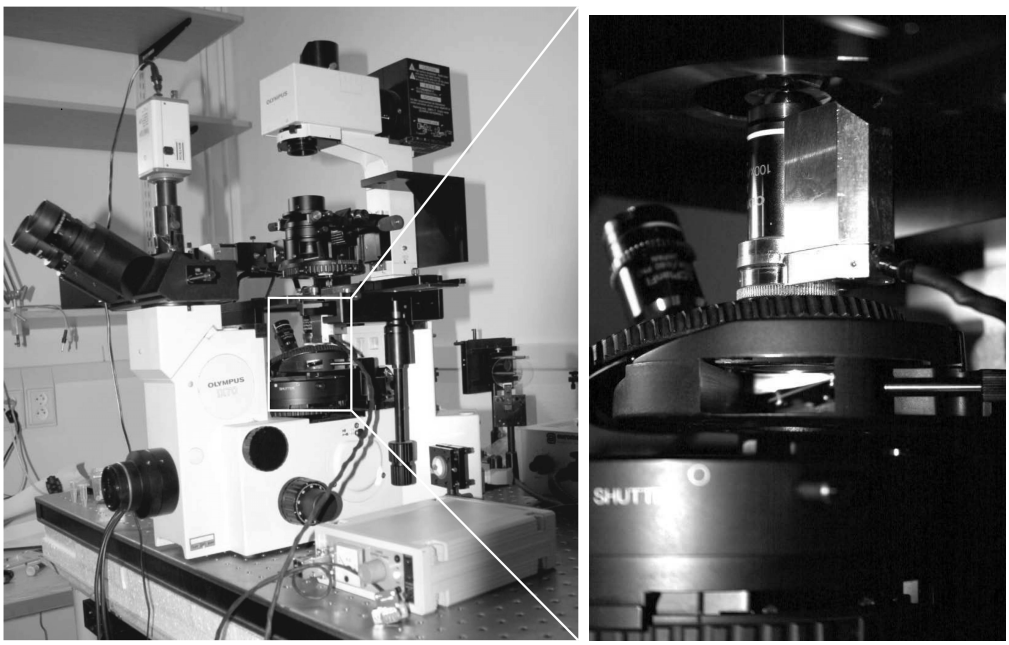

Figure 3. COP mounted on inverted microscope Olympus IX-70. View of the apparatus (left) and detailed view of the COP (right).

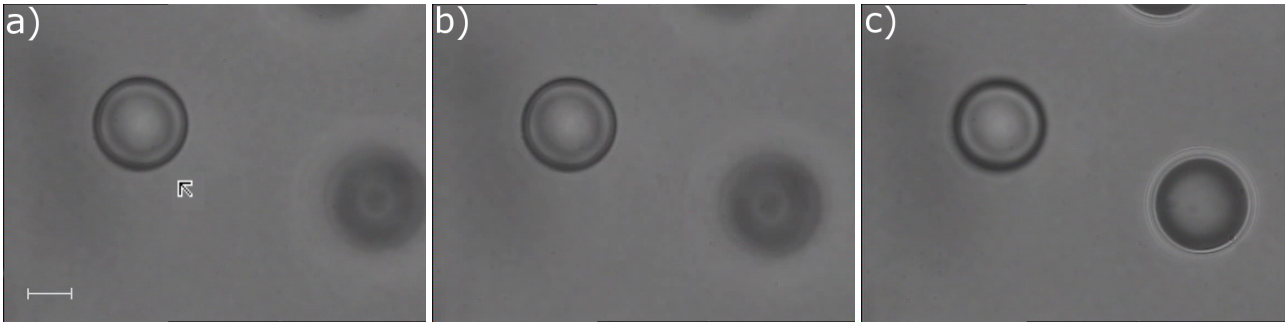

Figure 4. Arrow signed polymer microsphere with diameter 10 μm (4k-10 Duke Scientific) is trapped by COP in water solution. Object in the right part of images a) and b) laying on the microscope slide is blurred. Position of the optical trap is changed by vertical movement of the microscope objective and the image of the right particle is focused c). Trapped particle stays focused. Power in the focal point is 55 mW. Vector on the first picture has length 5 μm.

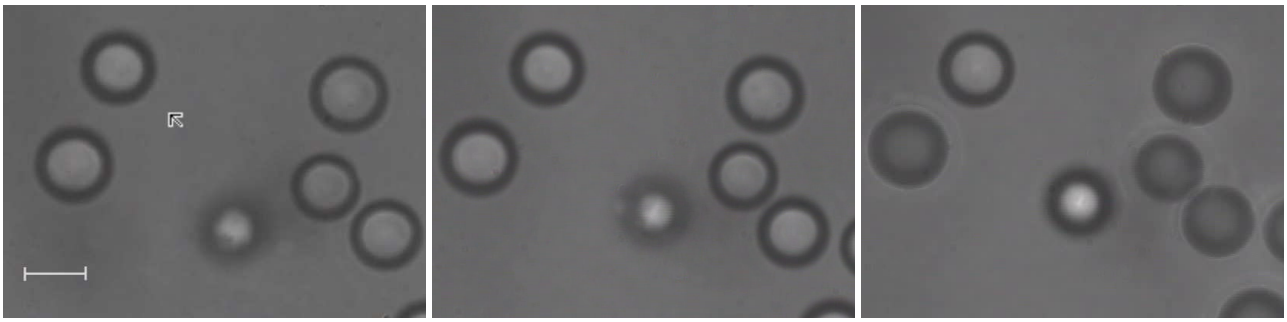

Figure 5. Arrow signed polymer microsphere with diameter 5 μm (4k-5 Duke Scientific) is trapped by COP in water solution. Particle is trapped by COP among particles of the same size and it moves towards to cover slip by vertical movement of the microscope objective. Sharpness of surrounding particles is changing. Power in the focal point is 55 mW. Vector on the first picture has length 5 μm.

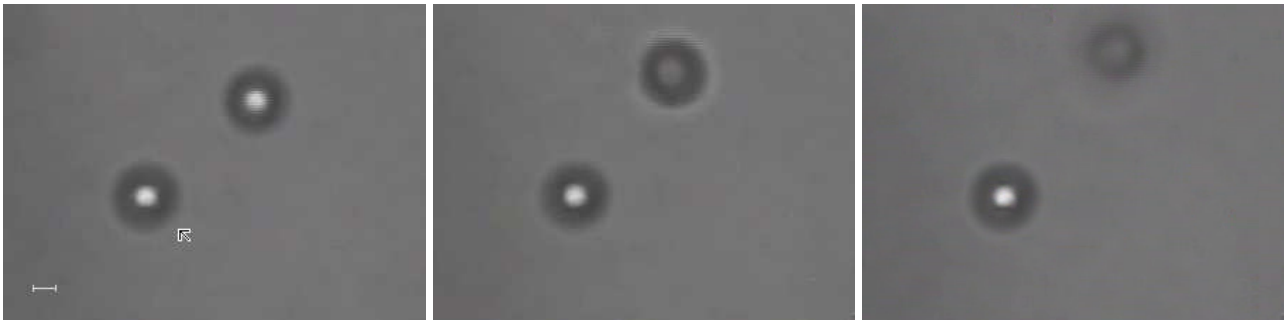

Figure 6. Arrow signed polymer microsphere with diameter 2 μm (4k-2 Duke Scientific) in water solution is trapped by COP. Object in right part of left image laying on the microscope slide is focused. The position of the optical trap is changed by vertical movement of the microscope objective and image of the right particle blurs. Trapped particle stays focused. Power in the focal point is 55 mW. Vector on the first picture has length 1 μm.

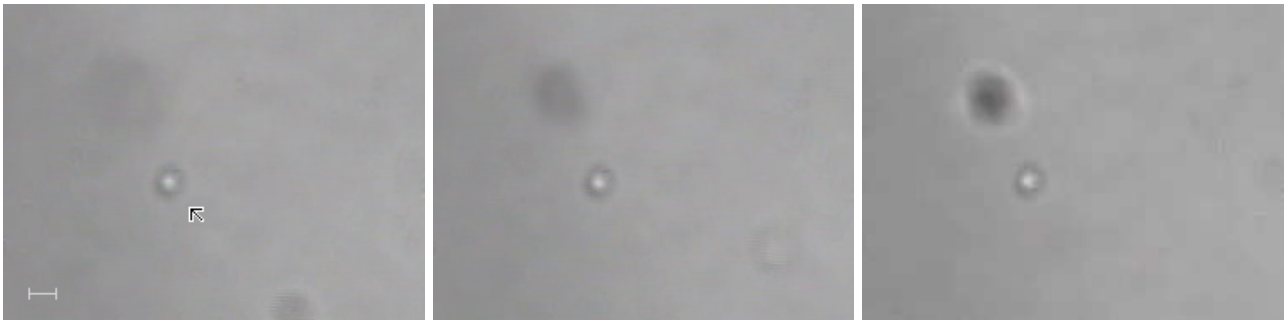

Figure 7. Arrow signed polymer microsphere with diameter 520 nm (3k-500 Duke Scientific) in water solution is trapped by COP. The position of the optical trap is changed by vertical movement of the microscope objective and image on CCD camera focuses. Power in the focal point is 55 mW. Vector on the first picture has length 1 μm.

We used upright microscope Olympus BX-50 in combination with microscope objective Olympus UplanApo 100x for verification of COP function in revert configuration (Fig. 8). As a specimen we used yeast cells *Saccharomyces cerevisiae*. Yeasts were diluted in water solution and enclosed by cover slip and microscope slide. Power in the focal point was keep at level 30 mW. Images were aquired by b/w CCD camera (Mintron, 63W1C) and digitized by framegrabber card (Picasso PCI-2SQ, Arvoo). Position of image plane is changed by lateral and longitudinal movement of the microscope stage. Image of trapped yeast is still focused (see Fig. 9, 10).

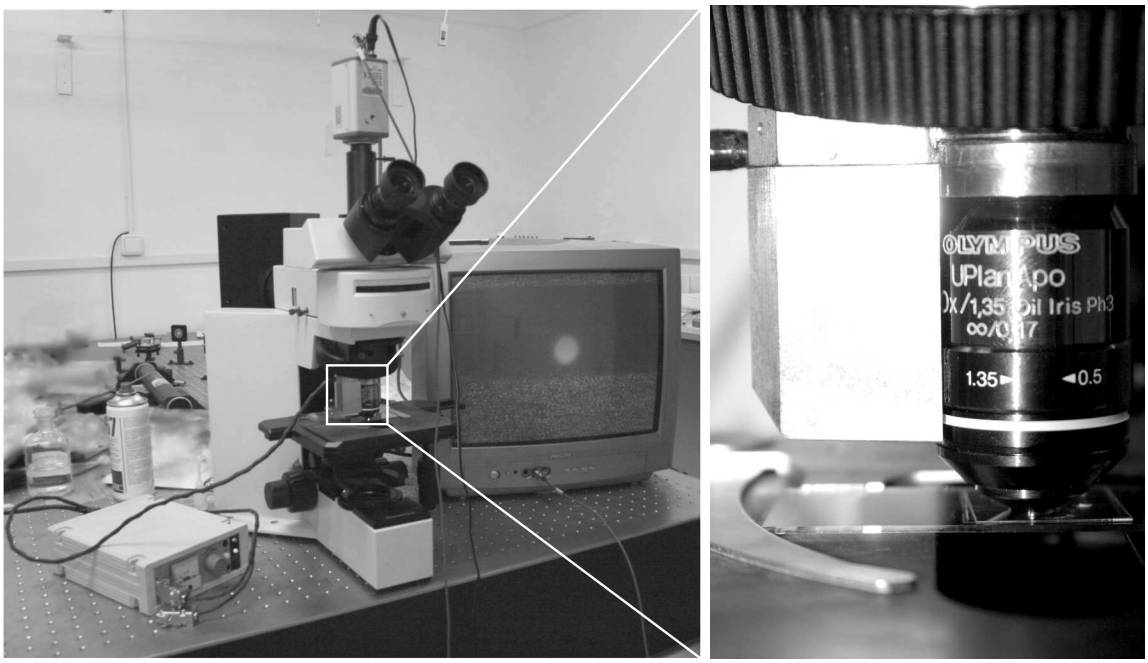

Figure 8. COP mounted on the upright microscope Olympus BX-50. View of the apparatus and current controler (left) and detailed view of the COP (right).

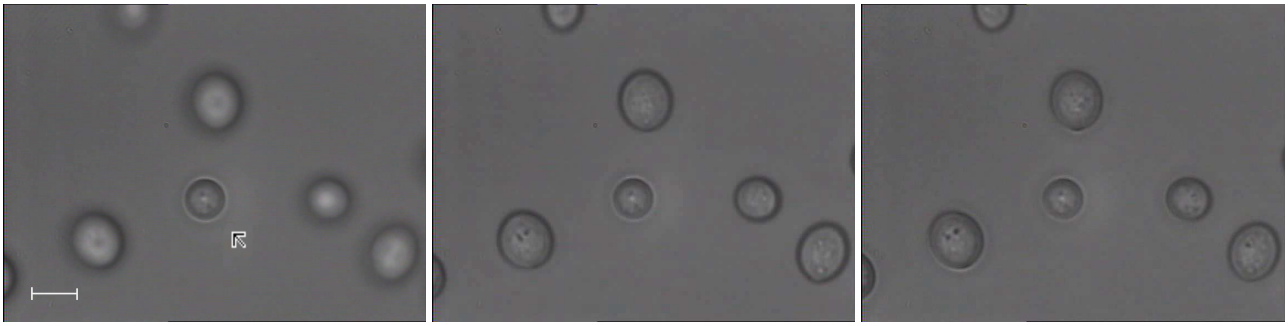

Figure 9. Manipulation with yeasts Saccharomyces cerevisiae (arrow signed), trapping power 30 mW. Yeast freely levitating in water solution is trapped by COP and the sample moves longitudinally. The image of the yeast is still focused, while the yeasts laying on microscope slide sharpen. Vector on the first picture has length 5 μm.

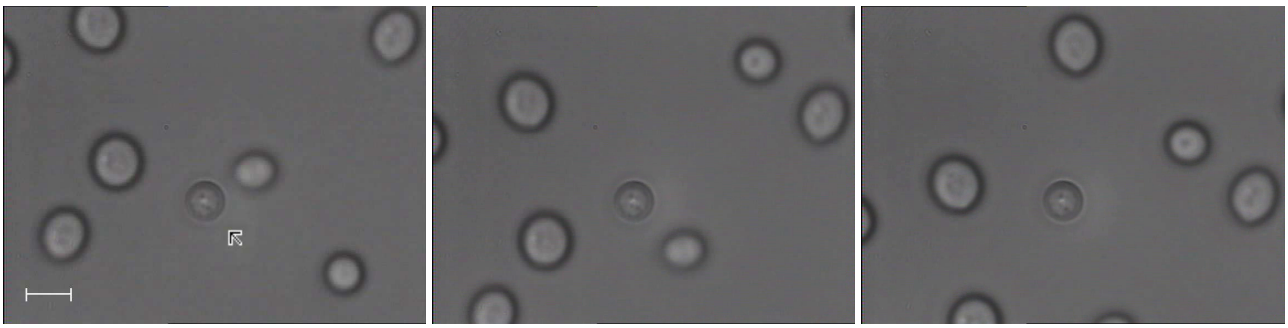

Figure 10. Manipulation with yeasts Saccharomyces cerevisiae (arrow signed), trapping power 30 mW. Yeast is trapped by COP and the sample moves transversally. Yeasts laying on microscope slide are moving to the bottom of the image, trapped yeast has same position. Vector on the first picture has length 5 μm.

4. CONCLUSION

The aim of this work is design and realization of compact optical twezeers (COP), tool to be used for optical micromanipulations on non-modified light microscope. COP solves troubles with guiding of laser beam into microscope by inserting COP between body of the microscope and the microscope objective. The COP does not need microscope for its functionality and may work standalone. All parts necessary for stable three-dimensional trapping are included. This solution preserves all microscope properties untouched and it is possible to introduce trapping techniques to many types of microscopes. The design is based on transformation of laser beam emanating from LD Sanyo DL 8031-031A with base transversal profile TEM_{00} and wavelength 808 nm. The goal of optical solution in program Zemax was to obtain collimated laser beam with minimal astigmatism. The simulation results suggested that optimal optical system for transformation of the beam consisted of aspherical lens and pair of anamorphic prisms. Mechanical and optical construction of COP was made with respect to spatial facilities of commercially available microscopes, mainly to the fact that optical parts of microscopes are optimized for visible spectrum of light. Most types of optical tweezers use epi-fluorescent port for insertion of laser beam, so changing of reflective elements in optical path is required. Presented construction of optical tweezers does not need for its work optical microscope and uses mechanical framework of microscope only for attaching COP. Collimated laser beam is then focused by microscope objective, which is screwed into Royal Microscope Society thread on emanating port of COP. Usability of COP with LD was tested on upright and inverted microscopes.

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