

Transversal Optical Binding and Optical Transfection with Dispersion-Compensated 12 fs Laser Pulses using MIIPS

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1 Optical Binding

1.1 Introduction

Optical tweezers are extremely powerful tools in the colloidal and biological sciences [1, 2]. Optical tweezers are widely used tools for example in microfluidics, measurement of Raman signatures in trapped particles, measurement of torque forces in flagellar optical motors, and so on. Whilst 2D control is well established, 3D control remains more elusive. In our research we investigate an aspect of optical trapping which is not fully understood. Previously, Burns et al. [3, 4] demonstrated an effect described as transversal optical binding. A two-dimensional optical line trap is created that weakly traps particles in the y-direction, but strongly traps particles in the x-direction. Burns et al. demonstrated that a transversal optical binding force exists between co-trapped particles and argued that the binding effect is the result of coherently induced dipoles in the spheres. In our experiments we revisit the work of Burns et al. and measure the transversal optical forces between two $1.5 \mu\text{m}$ silica spheres in water. We verify that stable sphere separations are observed that are equal to the wavelength of the coherent laser light in water. We also consider the binding from a theoretical standpoint and compute the optical forces from the Lorentz force and Maxwell stress tensor methods. We take into account the hydrodynamic interaction between the particles and the influence of glass substrate on the optical and hydrodynamic properties of the binding interaction. We intend to make progress on understanding the transversal binding forces and realise their implications for the field of optical micromanipulation and large scale biological particle control.

1.2 Method

Two particles are trapped in a line trap using an Argon-ion laser emitting at 514 nm. A tracking program is employed to monitor the trajectories of particles under the influence of the laser light. This data is analysed and any coherent effects and optical artefacts removed in order to accurately describe the particle pair potential as a function of

separation. This data is compared with the data acquired from the computational simulations.

1.3 Conclusions

Experimental results have verified computational simulations which model the optical binding effect. A greater understanding of light interactions at the microscopic scale will enable further research into the control and manipulation of biological particles. Optical binding adds another domain to the optical micromanipulation toolkit in the bid for full and comprehensive control of biological particles.

2 Photoporation using MIIPS

Understanding the process of transfection remains a topic of considerable interest in cell biology. Numerous methods have been employed to introduce foreign biological molecules into cells, including the gene gun, electroporation, viral-mediated gene transfer and micro-injection. Neither method covers all the requirements that cell biologists need such as cell specificity, high sterility and high cell viability. Transfection by photoporation is rapidly-developing technique whereby a focused laser beam permeabilises the cell membrane and allows extra-cellular biological material to cross the normally selectively-permeable membrane and permitting entry into the cell and thus allowing transcription and translation into the specified protein.

The choice of laser parameters for photoporation is a matter for in-depth consideration. The main variables which affect photoporation success are power, energy, spectral profile, temporal profile, beam profile, radiation time and of course, the type of cell and quality of conditions the cells are living in. Success is dependent upon careful control and balancing of all the experimental parameters. Studies by Vogel et al. [5] have indicated that the irradiance of the beam plays an important role in initiating dissection at the tissue level. Such principles can be considered at the cellular level also. Vogel et al. argue that there are a large range of irradiances below optical breakdown threshold which will lead to spatially confined thermal, chemical and mechanical effects at the focus of the beam, all of which are mediated by free-electron generation. Free electron generation is achieved by multiphoton absorption, subsequent impact ionisation and inverse Bremsstrahlung absorption events and initiated avalanche processes in order to create a plasma [5].

Photoporation using pulses of 120 fs has been proven successful [6], and recently even shorter pulses (sub 20 fs) have photoporated stem cells successfully [7]. Since the irradiance achievable is inversely proportional to pulse duration, a study into the success of even shorter pulses is required. However chromatic dispersion in the microscope optics will cause the pulse to be spread out in the temporal domain and hence decrease the achievable peak irradiance. Chromatic dispersion becomes a significant issue for pulse durations of less than 100 fs due to the broadband nature of such pulses. Multiphoton Intrapulse Interference Phase Scan (MIIPS) is an emerging technique for fully

compensating for all orders of dispersion [8].

MIIPS operates by inputting a reference phase function through the optics and generating a second harmonic beam with a nonlinear crystal. Since the second harmonic process is dependent upon the spectral information contained within the pump pulse, the resultant beam will contain information about the phase of the original pulse with with the encoded reference function. By measuring the spectral intensity generated by the second harmonic of the beam, an algorithm is used to work out the phase for the whole spectral range of the pulse. The dispersion induced phase alterations can be compensated for and therefore the pulse can be pre-compensated to deal with the dispersive optics with the net result that the pulse appears in its near transform-limited form at the desired location in the setup. In short, MIIPS can achieve a near transform-limited pulse duration and hence allow maximum irradiance to be achieved at the focus.

We will implement MIIPS in order to photoporate and transfect cells using a peak irradiance level not yet used by researchers. The ability to have greater control over the irradiance, while minimising damaging effects will enable us to investigate the success of transfection at larger irradiances. Construction of an ideal transfection 'recipe' would be indispensable for biological and medical research including drug delivery at the cell level and could form an integral part of a biophotonics workstation.

References

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