OPTICAL TRAPPING OF MESOSCOPIC TRANSPARENT/METALLIC PARTICLES BY SPATIALLY STRUCTURED LASER BEAM AND CHARACTERIZATION OF TRAPPED RBCs

by

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CERTIFICATE

This is to certify that the thesis entitled "**OPTICAL TRAPPING OF MESOSCOPIC TRANSPARENT/METALLIC PARTICLES BY SPATIALLY STRUCTURED LASER BEAM AND CHARACTERIZATION OF TRAPPED RBCS**" is being submitted by **RANJEET KUMAR** to the **Instrument Design Development Centre, Indian Institute of Technology Delhi**, for the award of the degree of **DOCTOR OF PHILOSOPHY**. This thesis is a record of bona-fide work carried out by him under my guidance and supervision. In my opinion the thesis has reached the standards fulfilling the requirements for the submission relating to the degree.

The results contained in this thesis have not been submitted to any other University/Institute for the award of any degree or diploma.

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Ranjeet Kumar

ABSTRACT

Optical tweezer (OT) using laser light has enabled the researchers to carry-out fundamental studies and peep into the microscopic world of natural sciences and engineering. In this thesis, multiparticle trapping of metallic nanostructures, photodamage-free isolation of electrically anisotropic rod-shaped live single cells *E. coli* bacteria and biological cells like RBCs and EAC cells, and then their characterisation using spatially structured and asymmetric **(SSA) laser beam** have been presented in seven chapters.

In Chapter 1 Fundamentals of optical tweezers (OT), radiation pressure, classification of the working regimes based on trapping wavelength and particles size, forces involved in OTs acting on transparent as well as metallic particles, development of OT, need of spatial beam shaping techniques (SLM, CHGs, e-beam lithographic phase-plate, multiple beam interferometry, holography etc.) and their merits and demerits in optical trapping schemes and up-to-date literature review is covered. Factors, like state of polarization of laser beam, aberrations of the optical system and the consequences of excitation of plasmon waves influencing the light-matter interaction in trapping have been discussed. Predominantly, the central role of SSA laser beam in multiparticle trapping has been augmented.

In Chapter 2 Generation of spatial beam patterns from fundamental mode TEM_{00} (also LP_{01}) emitted from red He-Ne laser light (Milles Garriot) using a 1x2 single mode fiber-coupler (SMFC) has been described. Here it has been investigated that due to presence of birefringence as a result of either of fibre-core asymmetry or a stress-induced waveguide cause the generation of LP_{11} modes. Further, spiral pattern of unit charge (sometimes more than one) obtained by interfering LP_{01} and LP_{11} modes at beam-splitter is demonstrated for real-time observation of minuscule power-fluctuations of a laser source (2mW, 532nm).

In Chapter 3 Multiparticle trapping and assembling of polystyrene beads using **SSA** laser beam emitted directly from the cavity of diode pumped solid state ($Nd^{3+}:YVO_4$) laser source (Laser Glow, Canada) operating at 532nm is described. It has been analysed that distributed intensity gradients of SSA beam has generated relatively larger focused spot size than pure TEM_{00} mode, smearing out the centrally confined power which in-turn effected weaker axial scattering force. SSA laser beam ($p-polarization$) driven OT has achieved in real-time photodamage-free multiple trapping of anisotropic rod-shaped live-microorganisms.

Chapter 4 *In-situ* clustering of unfunctionalized large diameter Au-NP (150nm and 254nm) by SSA laser beam near plasmon excitation wavelength window has been demonstrated. This

has been achieved because SSA beam has reduced the destabilizing axial-scattering force and created distributed potential wells corresponding to intensity gradients enough to trap the Au-NPs at the lowest reported value of trapping power so far (9.6mW). Therefore, first Ehrlich ascites carcinoma (EAC) cell was trapped in a sample containing unfunctionalized but distributed Au-NPs (254nm) and multiply enhanced scattering of trapping beam was observed – a confirmation of *in-situ* cluster formation. This study can be used for sensing, imaging, assessing the state of tumor/cancer progression, efficacy assessment of targeted load-delivery, phototherapy, non-linear spectroscopy and SERS etc.

In Chapter 5 Real-time line-pattern formation from trapped polystyrene spheres and tiny clusters of SDBS-functionalized single walled carbon nanotubes (SWCNTs) along the bright and dark region of fringes respectively using a crude, simple and cost-effective Michelson type interferometric optical tweezer (IOT) is presented. IOT is developed by coating a highly reflecting layer (~100nm thick by vapour deposition method) on one surface of cubic beam splitter which has freedom of changing the fringe-pitch and their orientation simultaneously. Despite the trapping wavelength (532nm) being blue-detuned with respect to two absorption peaks of SWCNTs (516nm and 545nm), this has been realized due to alternate intensity regions of Interferometric beam.

In Chapter 6 Simultaneous Euler buckling-free (threshold laser power for Euler buckling at object plane is 4.2mW) trapping of human red blood cells (RBCs) by SSA laser beam driven OT and IOT for their morphometry is investigated. Trapping of RBCs using SSA laser beam found two fold advantages. One, RBCs were trapped stably without causing any photodamage (computed threshold power at sample was 3.64mW- less than threshold value). Second, undesirable perturbations often induced into RBCs from the direct physical contact with glass-substrate to make them stationary in frequently employed techniques for morphometry, has been overcome. Morphology and refractive index (RI) of thus trapped RBC was measurement using fringe projection and phase-retrieval techniques. The obtained values of RI using this scheme are found close to standard values.

Chapter 7 provides conclusion of the research work presented in the thesis and perspectives of future work.

Dedicated to,

My parents and family members

and

In the memory of my Grand-parents

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