Resolving inter-particle position and optical forces along the axial direction using optical coherence gating

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Abstract: We demonstrate the use of coherence gating to resolve particle positions and forces in the axial direction. High depth resolvability (axial) and weak optical force (10^{-15} N) measurements in an optical trapping system is achieved.

OCIS codes: (020.7010) Laser trapping (110.1650) Coherence imaging

1. Experiment and results

In our experiment, a weak equilibrium position of the microsphere is obtained when the upward forces due to scattering forces and buoyancy balances the weight of the microsphere [1]. The axial trap stiffness can be increased by increasing the numerical aperture of the trapping optics [1]. In the common path LCI setup, we have both the reference and sample signals sharing the same optical path, thus dispersion and polarization mismatches between them are minimized [2]. The positions of the two reflecting surfaces of the microsphere are determined by taking the inverse Fourier transform of the detected spectrum.

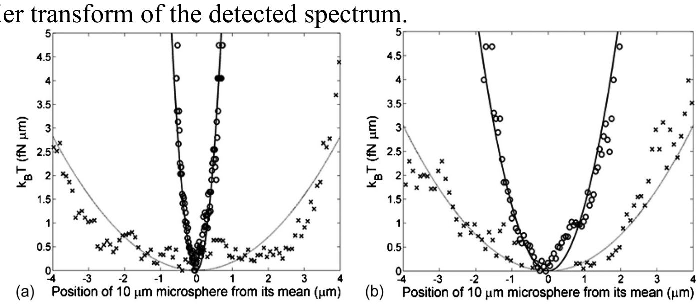

Figure 1: Optical potential profiles of a 10 µm microsphere measured with (a) objective lenses of 0.4 (**X**, $k_{0.4NA}$ = 1.46 fNµm^{-1}) and 0.7 (**O**, $k_{0.7NA}$ = 86.4 fNµm^{-1}) NA and (b) with (**O**, k_{50um} = 11.24 fNµm^{-1}) and without (**X**, k_{no50um} = 1.57 fNµm^{-1}) a 50 µm microsphere in the optical trap. The corresponding fitted optical potential profiles (lines) are also shown in the figure. The fitting accuracy as quantified by R-square is at least 0.82 in the experiments.

The LCI system is capable of measuring the dynamics of the 10 µm microsphere since the position displacement is within the linear detection range of our system (position sensitivity of 0.217 µm and linearity of over 100 µm). With a sampling time of 100 ms, 6,000 data points were obtained and the probability of the microsphere's displacement in a potential well, modeled as a Boltzmann distribution [1] , is obtained from the histogram of these data points. Figure 1a shows the optical potential energy of a trapped 10 µm microsphere obtained from the LCI system using two different NA objectives but with the same optical power of 2.3 mW. When the NA of the objective is increased from 0.4 to 0.7, the trap stiffness is increased by almost 60 times (1.46 to 86.4 fN.µm^{-1}). The re-focusing of an initial trapping beam through a microsphere can strongly influence the dynamics of the trapped particle through longitudinal optical binding [3]. In our experiment, a single stationary 50 µm microsphere, illustrated in Figure 1b, is used as the refocusing element. The trapping position of the 10 µm microsphere changed from 65 to 170 µm above the cavity floor when the 50 µm microsphere is removed. The measured trap stiffness is observed to increase by 7 times (from 1.57 to 11.24 fN µm^{-1}) in the presence of the 50 µm microsphere, as expected from the resulting increase in the NA of the optical trap. Based on the values of the trap stiffness, the effective NA of the 50 µm microsphere is inferred to be between 0.4 and 0.7. The measurements of both the absolute positional shift of the 10 µm microsphere and the increased trap stiffness due to the re-focusing of light by the 50 µm microsphere highlights the strength of LCI in the direct visualization of inter-particle optical mechanical interactions [3, 4]. The authors acknowledge initial discussions with Prof Kishan Dholakia. research grants SCS-BU0052 and RP C-015/2007 from A*STAR, RGM39/06 from the MOE and additional financial/technical from Einst Technology Pte Ltd. (Singapore).

2. References

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