How stiffness of optical trap depends on proximity of dielectric interface

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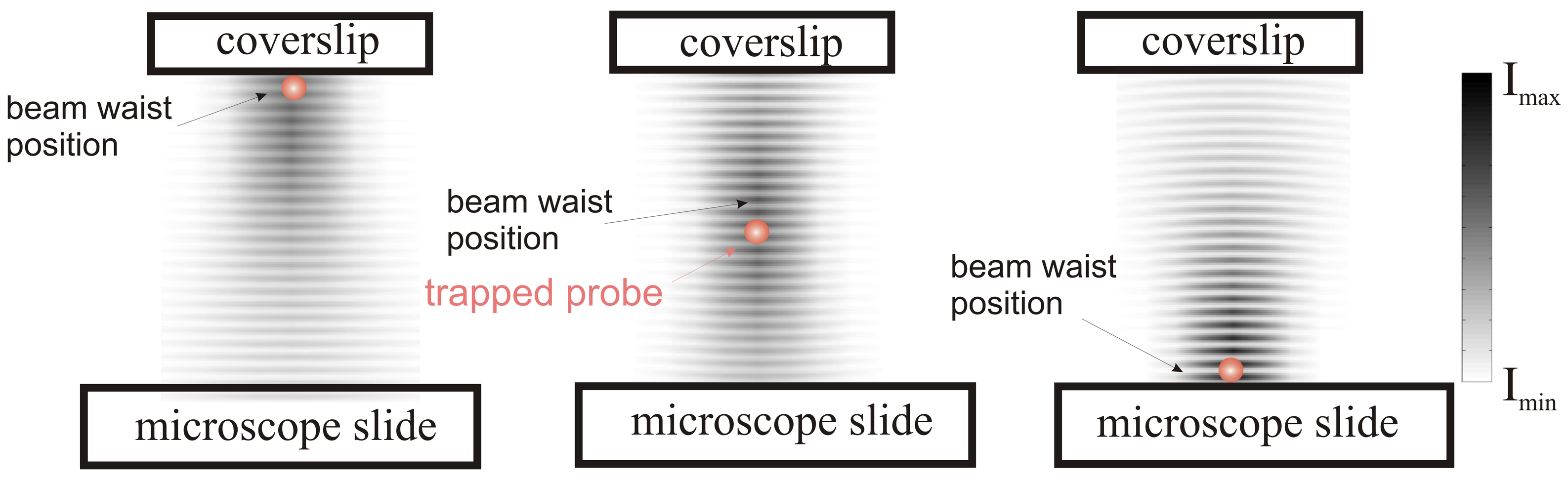
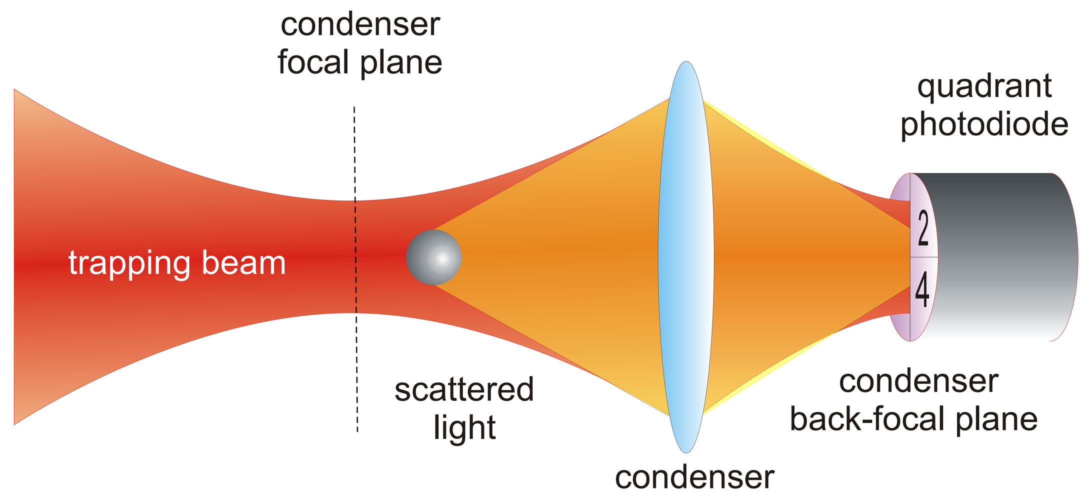
ABSTRACT

When a probe confined in a single focused laser beam approaches the surface, it is getting more influenced by the retroreflected beam. This beam interferes with the incident one and a weak standing wave (SW) is created, which slightly modulates the incident beam. We studied experimentally how this phenomena influences the optical trap properties if SW is created using surfaces of two different reflectivities. We used polystyrene probes of diameters 690 nm and 820 nm, tracked their positions with quadrant photodiode (QPD) and analysed their thermal motion to get the axial trap stiffness along optical axis.



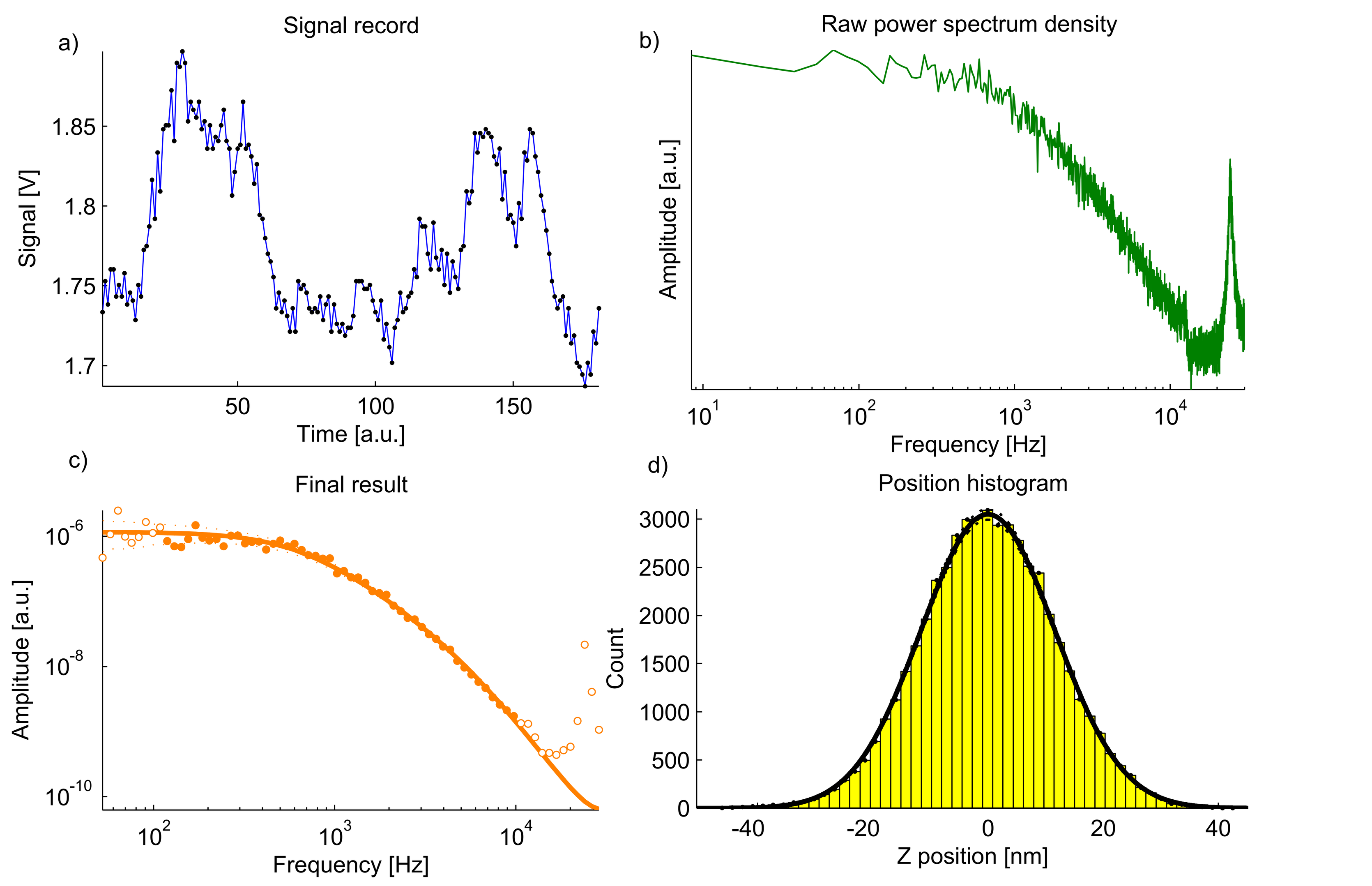
- incident beam reflects on common glass bottom slide
- interference creates weak standing wave modulation on the gaussian beam
- position of bead in the standing wave depends on distance between trapping beam waist and bottom slide
- axial stiffness of optical trap depends on the position of the trapped probe in the standing wave
- therefore, the axial stiffness of optical trap depends on the distance between beam waist and bottom slide

PARTICLE POSITION DETECTION



- light scattered on the trapped probe interferes with the incident beam and creates interference pattern
- quadrant photodiode detector is placed in the back-focal plane of condenser lens
- the intensity on detector is directly proportional to distance between the trapped particle and trapping beam waist

DATA PROCESSING

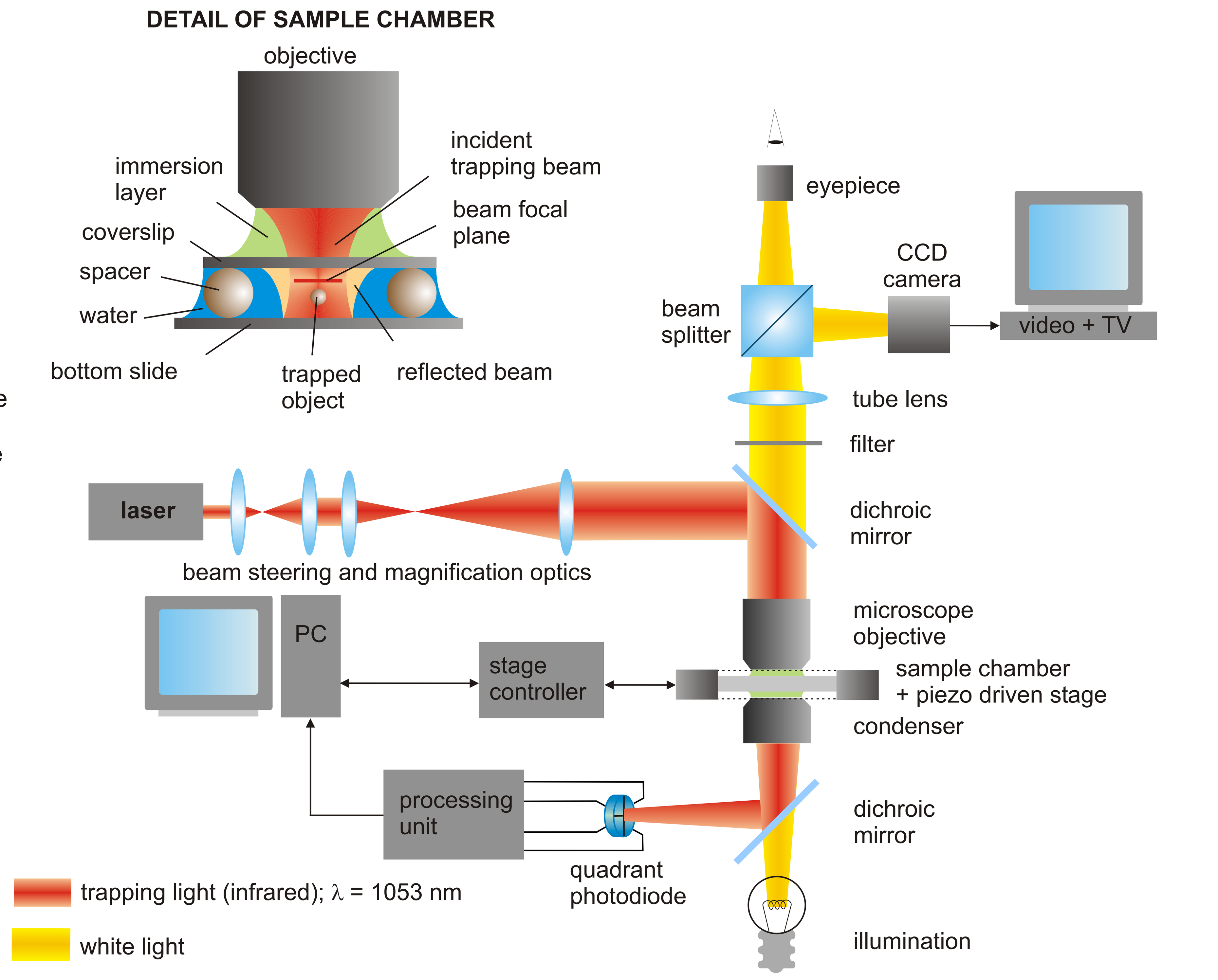


a) record of particle positions during short time interval, the black points show that recording frequency was high enough to follow Brownian motion of the particle
b) power spectral density (PSD) of the particle positions is aliased lorentzian
c) noise was removed from PSD with boxing method, fitting interval was set to 110 Hz -- 10 kHz so that mechanical noise from apparatus and high-frequency noise from electronics did not influence the final fit; trap stiffness is calculated from corner frequency of PSD
d) after calibration of the detector, position histogram was generated in each point to estimate the axial extent (height) of the trapping space

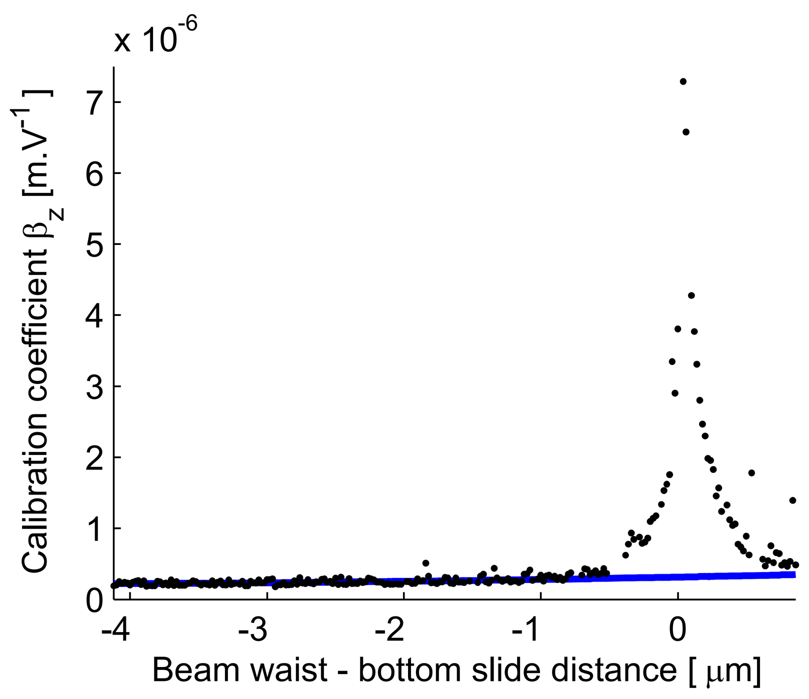
CONCLUSIONS

We demonstrated, that interference of back-reflected light with incoming beam even above an ordinary glass interface of reflectivity *R* = 0:4% creates a standing wave strong enough to influence significantly the positions of the trapped particle. The trap stiffness along the optical axis changes periodically with respect to the standing wave nodes and antinodes. The changes in stiffnesses are noticable more when using probes sensitive to the standing wave. This effect is further enhanced when reflective slide is used instead of an ordinary glass.

EXPERIMENTAL SETUP



- trapping beam is enlarged with two telescopes
- microscope objective (oil immersion, N. A. 1.25) focuses beam into sample chamber
- sample chamber is moved axially with 3 nm accuracy (stage Physik Instrumente PI-517.3C with capacitive sensors)
- beam passes through condenser lens and impacts quadrant photodiode, which serves to measure trapped particle position
- sample chamber is imaged on both camera and eyepiece
- sample thickness is defined with spacers (polymer spheres of diameter 9.14 μm)
- polymer probes of diameter 690 nm and 820 nm were tested (Duke Scientific, R700 and R 800)
- common glass bottom slide (reflectivity R=0.4 %) and coated glass (R=13 %) were used



MEASUREMENT PROCEDURE

- axial step 40 nm
- in each point gathered 50 000 particle positions with 60 kHz rate
- axial trap stiffness was calculated from lorentzian corner frequency
- equipartitional theorem was used to calibrate position detector
- trap near dielectric interface loses its harmonic behavior
- calibration of detector near bottom slide was extrapolated, because the equipartitional theorem is valid only for particles trapped in harmonic potential well

ACKNOWLEDGMENTS

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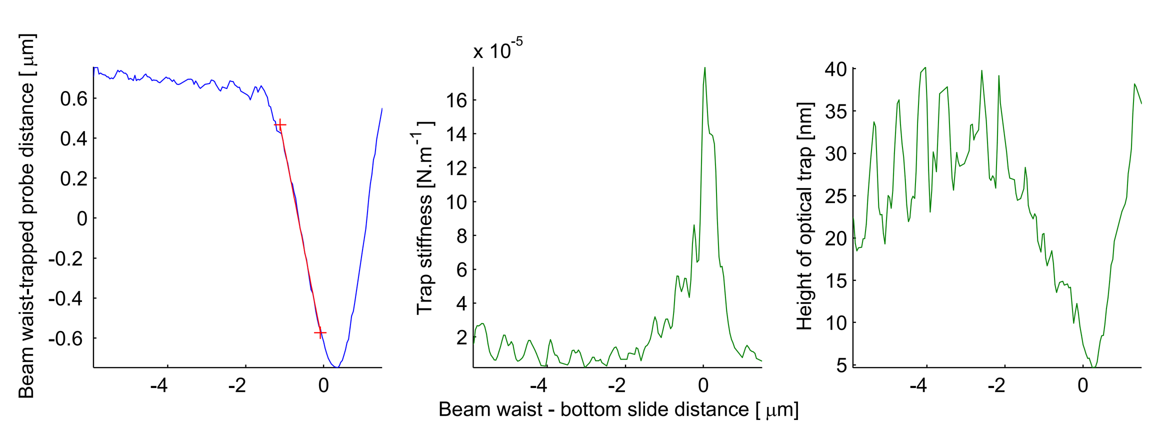
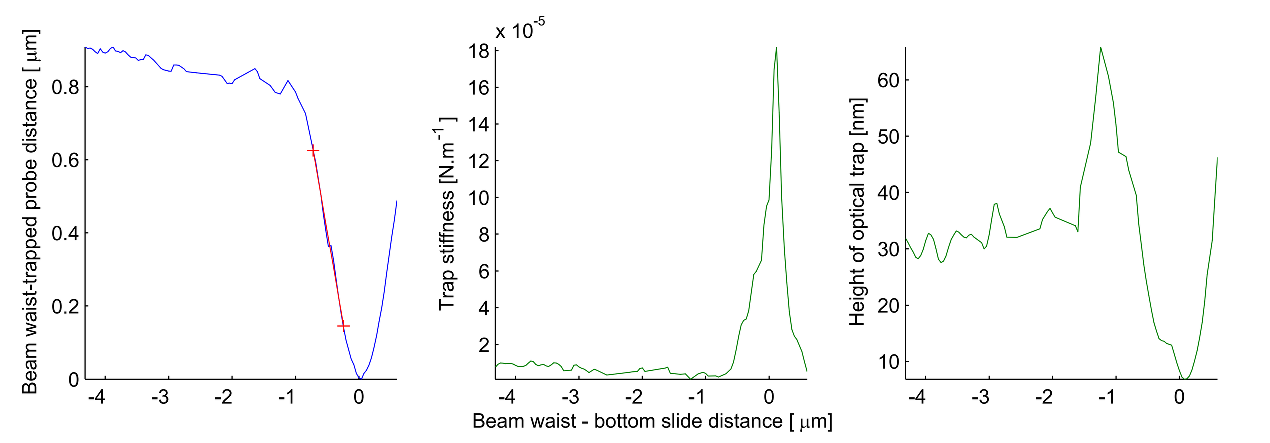
probe diameter 690 nm

820 nm

reflectivity

R = 0.4 %





R = 13 %