Measuring the pressure of light with an adaptive holographic interferometer based on sillenite-type crystals

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We present a novel technique for the measurement of the radiation pressure of light. Intensity-modulated radiation pressure causes oscillations of a reflecting surface that are detected by an adaptive holographic interferometer. It is possible to detect amplitudes of oscillations of approximately 50 pm, which correspond to pressure changes of 10^{-5} Pa.

1 Introduction

In 1873, J.C. Maxwell derived a formula to describe the radiation pressure of light [1]:

$$P = \frac{I}{c}(1+R) \qquad (1)$$

The pressure P is proportional to the intensity of the light, furthermore it depends on the speed of light c and the reflectivity of the surface R. Nevertheless it does not explicitly depend on the wavelength.

As it is a very small quantity (e.g. light with an intensity of 1 mW/mm² exerts pressure of 6,6 µPa on a fully reflecting surface), often other effects are perturbating [2]. Therefore the measurement is challenging and high precision is necessary.

2 Measuring principle and experimental set-up

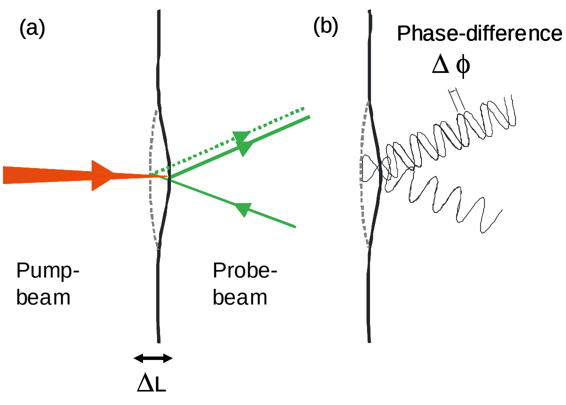

Fig. 1 *Principle of the measurement: (a) Thin membrane deviated by the radiation pressure of light of a focused laser beam. (b) Induced phase-difference to the probe-beam.*

To measure the radiation pressure of light, a thin membrane is illuminated by a focussed laser beam, see Fig. 1 (a). Changes in the intensity of this pump-beam cause deviations ΔL of the membrane. These result in phase-differences ΔΦ of the probe-beam, illuminating the membrane from its opposite side, as shown in Fig. 1 (b).

Periodic phase-modulations caused by periodic intensity-modulations of the pump-beam can be detected with the interferometer sketched in Fig. 2. To enhance the sensitivity of the interferometer, a dynamic hologram written in a BSO-crystal is used as a beamsplitter [3]. It acts as a high-pass-filter and therefore suppresses external low-frequency noise [4]. To further enhance the sensitivity and to exclude perturbating thermodynamic effects, the membrane is placed inside a vacuum-chamber.

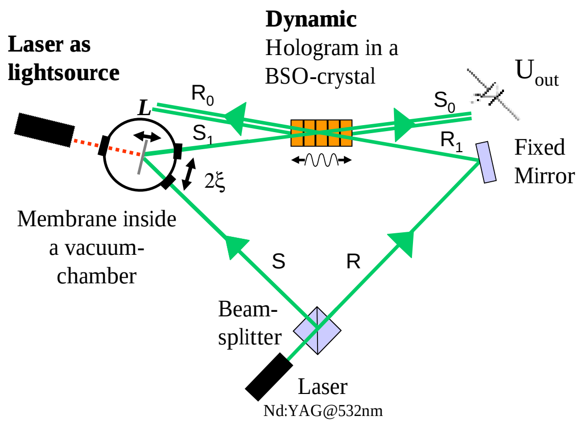

Fig. 2 *Experimental set-up*

3 Measured radiation pressure of light

In Fig. 3 the measured dependence of the amplitude of oscillation ΔL of the membrane from the modulated radiation pressure of light is shown. The measurement was performed with three different pump-lasers at wavelengths λ = 405 nm, 532 nm and 1554 nm. Desiting from the known wavelength-dependence of the membrane's reflectivity, the signal is independent from the wavelength of the illuminating pump-light and proportional to it within the estimated error.

The minimal measurable amplitude of oscillation is about 50 pm, corresponding to a modulated radiation pressure of 10^{-5} Pa.

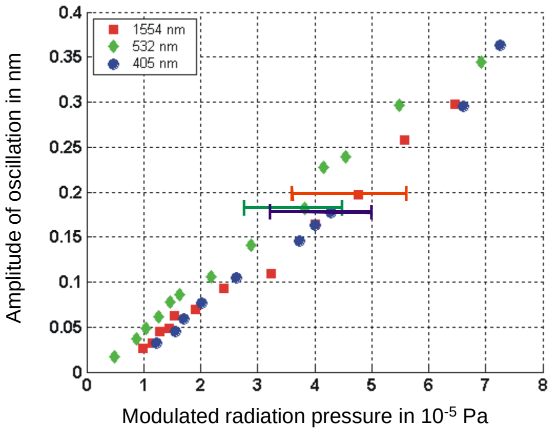

Fig. 3 *Measurements of the modulated radiation pressure of light of three different pump-lasers (λ = 405 nm, 532 nm, 1554 nm).*

4 Exclusion of pertubating effects

To verify that the movement of the membrane is not due to a pertubating thermodynamic effect, the pump-laser was chopped with a frequency of Ω = 1 kHz and the output-signal of the interferometer recorded at the oscilloscope, see Fig. 4.

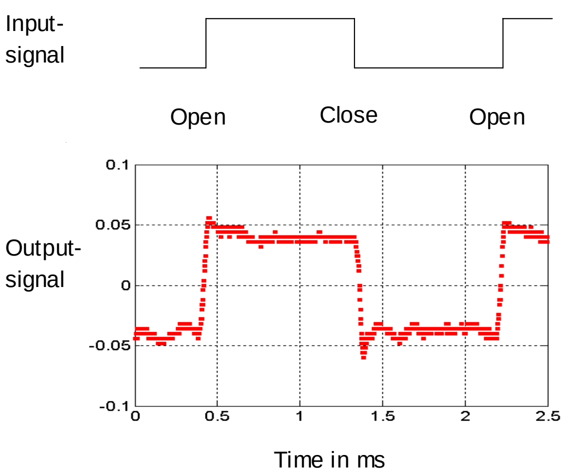

Fig. 4 *Output-Signal of the interferometer on the oscillopcope resulting from a pump-beam chopped with Ω = 1kHz*

In the thermodynamic case the slopes would correspond to the heating and cooling process of the membrane. Because of the symmetry of the slopes and the fast time-scale on which the interferometer is reacting, thermodynamic effects can be excluded,

From this it can be concluded that the signal is caused by the on/off-switching of the radiation pressure of the pump-light.

5 Summary and Conclusion

The radiation pressure of light was measured with an adaptive holographic interferometer. Pump-laser-beams with periodically modulated intensity at wavelengths λ = 405 nm, 532 nm and 1554 nm illumitated a thin highly reflective membrane. That movement was measured via the phase-modulation of a probe-laser-beam in an interferometer. To enhance the sensitivity of the interferometer by suppressing low-frequency-noise, sillenite-type-crystals were installed as dynamic beamsplitters.

Using that technique, changes in the radiation pressure of the pump-beams in the order of 10^{-5} Pa could be measured, corresponding to deviations of the membrane of approximately 50 pm.

Furthermore, it was proved that these measurements did not depend on the wavelength, which was shown for the band of 405 nm (violett) to 1554 nm (infrared).

From further measurements it could be concluded that the measured signal is caused by the radiation pressure of light and thermodynamical effects could be excluded.

References

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