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Measurement of copper vapour laser-induced deformation of dielectric-coated mirror surface by Michelson interferometer

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Abstract. A Michelson interferometer-based technique has been used to measure the deformation of dielectric-coated mirror, caused by an incident repetitive pulsed laser beam with high average power. Minimum measurable deformation of 17 nm is reported.

Keywords. Michelson interferometer; interferogram; high reflectivity mirror; nanoscale deformation.

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1. Introduction

The stringent requirement on the performance of a high-power laser system is often constrained by the minute deformation of high reflectivity multilayer dielectric mirrors used in laser system or for transporting the laser beam. Different methods based on interferometric [1] and wavefront measurement technique [2] have been reported for measuring such deformation with the sensitivity of $\lambda/100$ (where λ is the wavelength of the probe beam).

In this paper, we report the use of a Michelson interferometer to accurately measure the optical surface deformation, caused by irradiation by a copper vapour laser (CVL) beam. This deformation causes a change in interference pattern within the reference interferogram from which the deformation amplitude is extracted.

2. Experimental set-up

Figure 1 shows schematically the experimental arrangement for the Michelson interferometer. A He–Ne laser at 632.8 nm, expanded by a 30× beam expander, serves as the

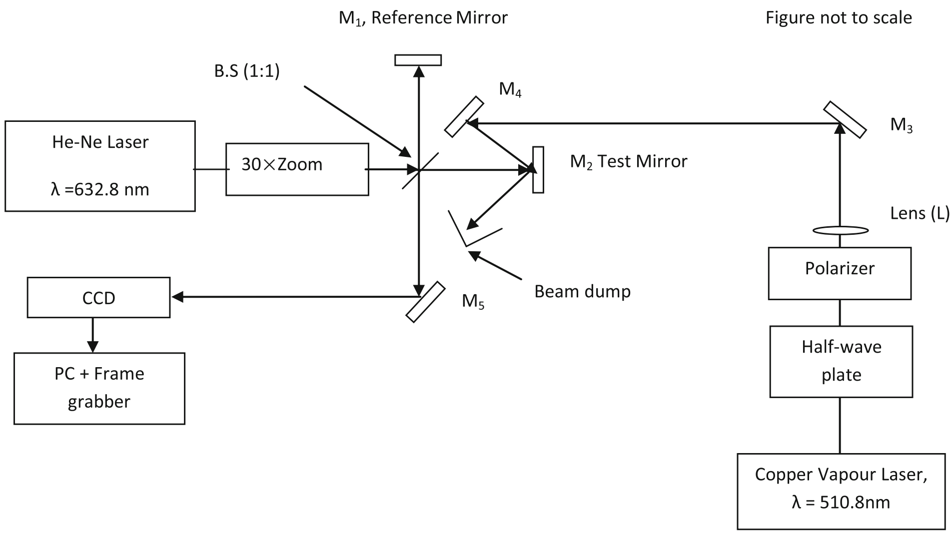

Figure 1. Basic experimental set-up for Michelson interferometer.

probe beam for the interferometer. Straight fringes are purposefully produced by appropriate adjustment of the orientation of the interferometer mirrors. A CCD camera and a frame grabber are used to capture the images for digital image processing. A pulsed CVL beam focussed by a lens (L) of focal length 100 cm irradiates the surface of the test mirror (M_2). The CVL beam spot size is kept small in comparison with the probe beam size such that the edges of the probe beam interferogram provide a real-time reference with respect to which the deformation in and around the central part illuminated by the CVL beam can be measured. In this way, uncertainties, arising from possible drift in the interferogram fringes owing to environmental or mechanical changes, can be avoided. The pixel values at measurement locations are used to compute the deformation. The power of the incident CVL beam is changed by the combination of a polarizer and a half-wave plate and monitored by a power meter.

3. Result and discussion

Figures 2a and 2b show the interferograms before and during the irradiation by the CVL beam at 511 nm. The variation of fringe intensity across the horizontal cursor line is shown on the top of each interferogram. The general shifts in the fringe and intensity pattern are caused by environmental changes. We measure the dark fringe separation at the reference position (at the top edge), ΔP, and the dark fringe deformation, δP, at maximum deformation position. The maximum mirror surface deformation is given by

$$S = \frac{1}{2} \times \frac{\delta P}{\Delta P} \times \lambda_{\text{probe}}. \tag{1}$$

This straightforward approach fails when the deformation is large and spreads close to the edges, rendering measurement of δP erroneous. In this case, we measure the dark fringe

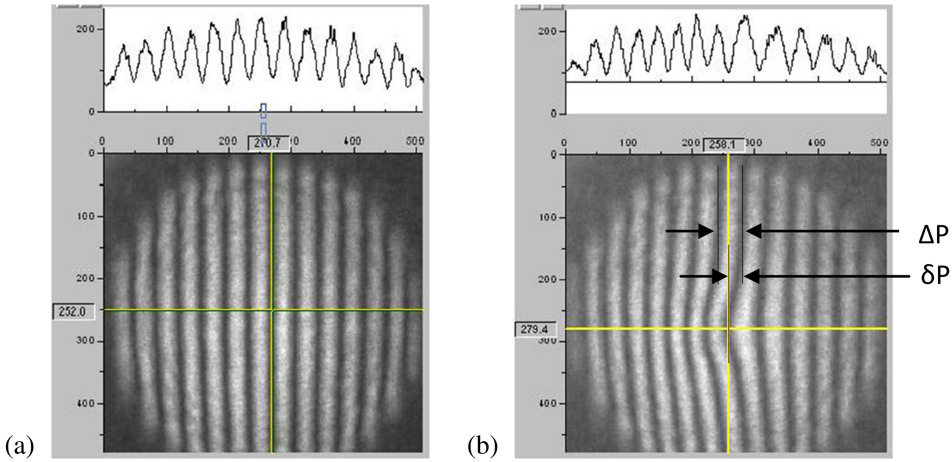

Figure 2. Interferogram (**a**) reference (without CVL), (**b**) with CVL (7.7 W, 5 mm spot size).

profile pixel data along the fringe in the vertical direction by moving the horizontal cursor in steps of 10 pixels, and fit it to a Gaussian distribution. The 'reference pixel' for δP measurement is then determined from the extrapolated wings of the fitted curve where the variation in horizontal pixel value converges to less than one pixel.

From simple error propagation considerations for independent measurement of δP and ΔP, the minimum measurable deformation is given by

$$\mathrm{d}S = S \times \left[\left(\frac{\mathrm{d}(\delta P)}{\delta P} \right)^2 + \left(\frac{\mathrm{d}(\Delta P)}{\Delta P} \right)^2 \right]^{1/2}, \tag{2}$$

where the smallest measurable fringe shift (δP) is the error ($\mathrm{d}(\delta P)$) in measuring the same, which is taken as two pixels. From repeated measurements we find $\Delta P = 37$ pixels (mean) with a spread much lesser than 1 pixel. For worst-case estimation, we again take $\mathrm{d}(\Delta P)$ $= 2$ pixels. The corresponding 'minimum measurable deformation' works out to 17 nm.

Three commercial mirrors with multilayer dielectric coating on BK7 and fused silica substrates, and reflectivity more than 98% were tested for a range of intensities. Typical interferograms observed on a BK7 substrate sample at different intensities are shown in figure 3. Figure 4 shows the variation of deformation with average intensity for the BK7 substrates for different CVL beam spot sizes. The results show a spot size dependence, which agrees well for independent samples, with that expected from a simple analytical model [3] given by the equation

$$S \approx \frac{\alpha}{4\kappa} \left(\frac{P_a}{\pi \omega^2} \right) \times \omega^2,$$

where α and κ are the thermal expansion coefficient and thermal conductivity of the substrate, respectively, P_a is the average absorbed power and ω is the spot size. The difference in absorptivity of the coating on the two BK7 substrate mirrors (2″ and 3″ diameter) would need to be determined to resolve the difference in the slope of the two sets of

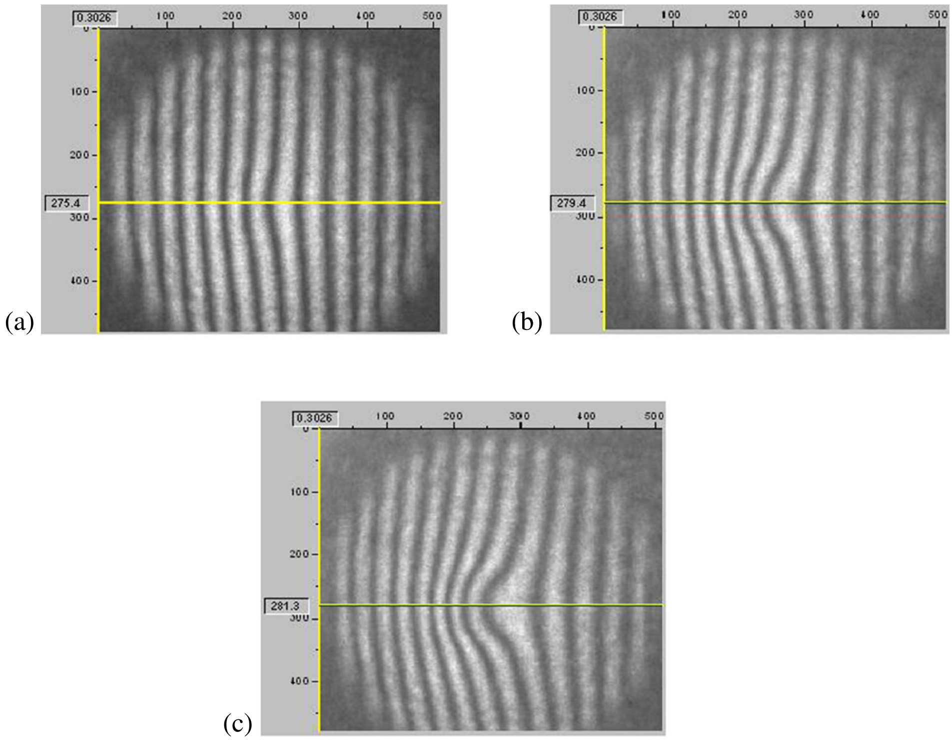

Figure 3. Interferograms obtained for a power density of (**a**) 20.9 W/cm^2, (**b**) 56.0 W/cm^2 and (**c**) 78.4 W/cm^2 (initial spot size ∼5 mm).

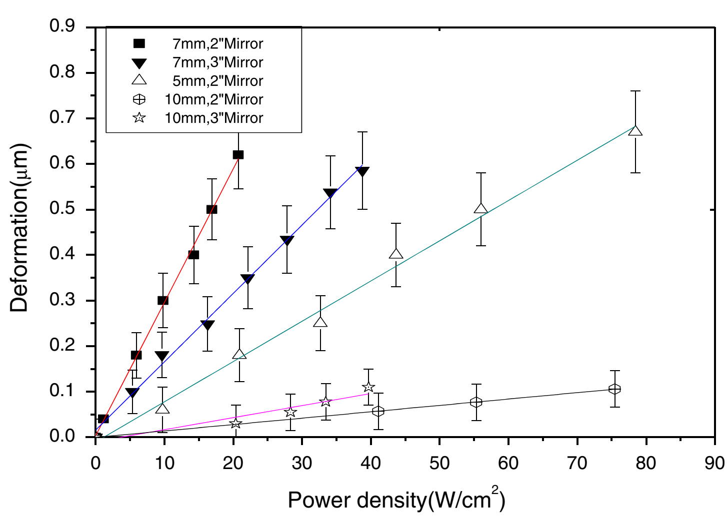

Figure 4. Deformation vs. average power density for mirrors with BK7 substrate. The inset data show spot size and mirror diameter.

curves. On the other hand, the sample with fused silica substrate showed no detectable deformation even up to power density 450 W/cm^2, which, again, cannot be attributed only to difference in substrate material properties, as α/κ for BK7 and fused silica are 6.37×10^{-6} m/W and 0.33×10^{-6} m/W, respectively, differing by a factor of only 19.

4. Conclusion

In conclusion, we have presented a simple method for measuring the absolute deformation of high-reflectivity mirrors under the repetitive laser pulse irradiation with high average power. Measurement on a single interferogram eventually helps to measure deformation more accurately. So this technique can be used for optical surface deformation under repetitive laser pulse.

Acknowledgement

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