Precision surface profile measurement using femtosecond pulse laser

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We report high precision surface-profile metrology using femtosecond pulse lasers as a low-coherence interferometric light source. Unequal-path non-symmetric Twyman-Green interferometer is configured to test large-sized optics with small-sized reference surfaces, which is only feasible with ultrafast mode-locked pulses of the repeated temporal coherence and high spatial coherence. The measurement result of a mirror is demonstrated as well as comparison with the results using conventional monochromatic light sources.

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1. Introduction

Interferometry has been widely used for both optical testing and measuring surface profile of industrial samples [1], which shows distinctive characteristics depending on which light sources are adopted. Monochromatic light sources such as He-Ne laser are frequently used for phase-shifting interferometry to test optics such as mirrors or lenses, thanks to the high temporal and spatial coherence of the light sources. Low-coherence interferometry that is free from 2π-ambiguity, however, takes advantage of low-temporal coherence of broadband light sources.

The ultra-short mode-locked femtosecond laser has brought a drastic improvement in the field of metrology using light source's unique characteristics [2]. Femtosecond pulse laser under precise frequency control makes the measurable range and accuracy much better in the field of absolute distance measurement [3]. It also brings precision surface metrology further developed by means of both the high spatial coherence and periodic temporal coherence of femtosecond laser [4].

In this paper, the advanced interferometer with a femtosecond laser is suggested for precision surface metrology of a large optics. Using a femtosecond pulse laser at interferometry, advantages of both interferometer using a monochromatic light and a interferometer using a broadband light are taken selectively as shown in figure 1. Due to repeatedly arising pulses with high spatial coherence and low temporal coherence, it is possible to not only implement non-symmetric and unequal path structure but also remove parasitic interferograms. Since femtosecond laser is highly stabilized to a timing reference, the interferometer can be applied to precision calibration as well.

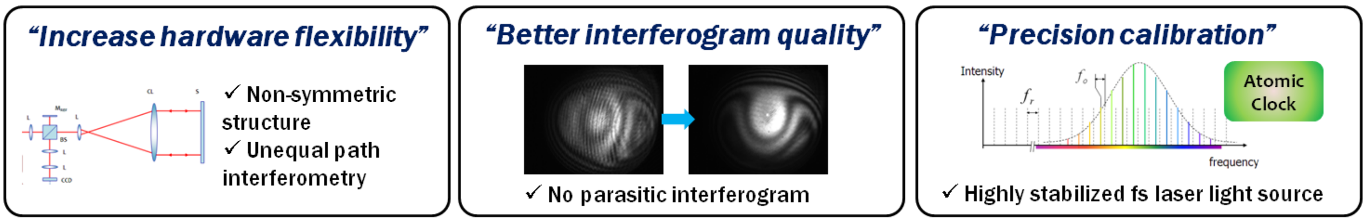

Fig. 1 Advantages of large-scale Profilometry using low-coherence interferometry

2. Precision surface metrology using repetition rate sweeping of a femtosecond laser

2.1 Optical configurations

Figure 1 shows the schematic diagram of the interferometer for precision surface metrology using femtosecond laser. The entire system is classified into two parts; a light source with its control part and an interferometer part. Femtosecond laser oscillator produce pulses under precise frequency control. Signals in the control part are stabilized by atomic clock as a timing reference. Pulses from the oscillator are passing through a collimating lens, and divided beams by a beam splitter head towards a reference surface and a target surface each. Beams reflected from each surfaces interfere and imaged at CCD with an imaging lens. After that, analysis on interferograms with appropriate data processing such as peak detection and Fourier domain analysis yield surface profile information.

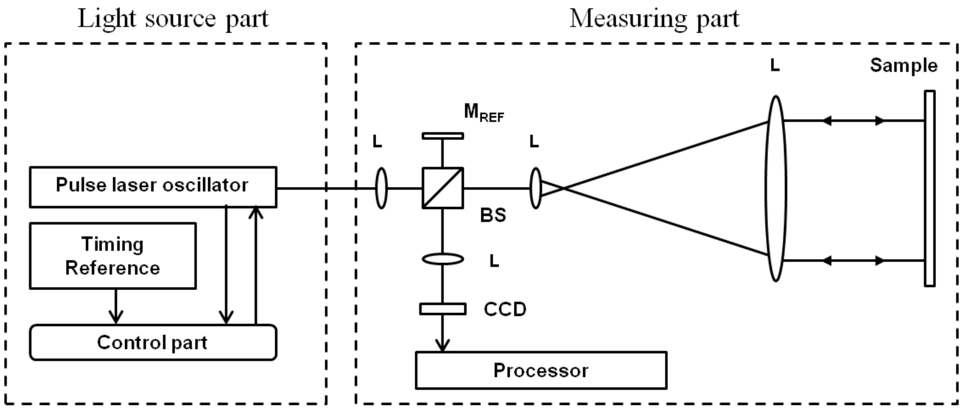

Fig. 2 Interferometer for precision surface metrology using a femtosecond pulse laser as a light source.
BS: beam splitter, L: lens, M_{REF}: reference mirror, CCD: charge-coupled device

2.2 Experimental results

After obtained interferograms from the interferometer get through appropriate analysis algorithm, the surface profile of a flat mirror is given as figure 3(a). For comparative testing, the same experimental procedures were executed except replacing femtosecond laser with monochromatic light sources. Surface profiles of the same mirror are demonstrated with both He-Ne laser (figure 3(b)) and laser diode (figure 3(c)). Compared to the contour map which is stained by unwanted high frequency modulations due to stray reflection, the surface profile from interferometer with femtosecond laser shows better quality without any parasitic interferogram.

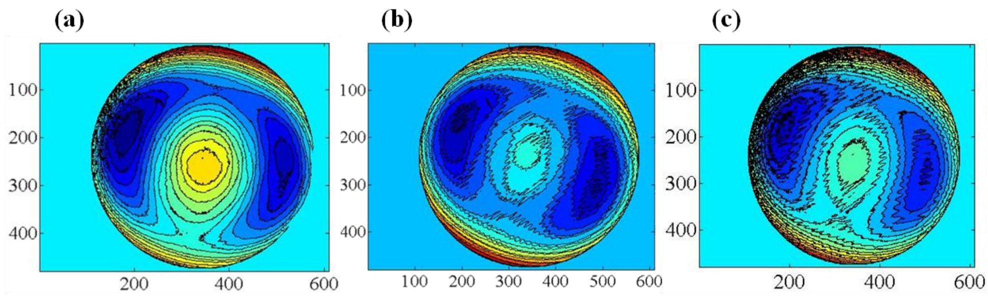

Fig. 3 Two dimensional contour map of the surface profile of a mirror when different types of light sources are used.
(a) a femtosecond laser (b) a He-Ne laser (c) a diode laser

3. Conclusions

Surface measurement utilizing unique characteristics of femtosecond laser has been described with experimental results. The repeated temporal coherence and high spatial coherence allowed unequal-path and non-symmetric configuration, which enables implementing low-coherence interferometry with further hardware flexibility. Unlike conventional phase shifting interferometry using monochromatic light sources, there wasn't any noticeable parasitic interferograms by stray reflections due to low coherence of ultra-short pulses. The interferometer with femtosecond laser can be utilized to profile diverse sizes and types of optics precisely without hardware modification.

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