Two-wavelength Grating Interferometry for Extended Range MEMS Metrology

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Abstract

Diffraction gratings integrated with MEMS has many applications as they can offer shot noise limited sub-nm displacement detection sensitivities but are limited in range. A two-wavelength readout method is developed that maintains high sensitivity while increasing the detection range from 105nm to 1.7um assuming sensitivity is maintained at >50% of the maximum sensitivity.

Keywords: Optical Sensing, Grating interferometry, MEMS metrology

1 INTRODUCTION

Diffraction Grating Interferometry is an attractive method for MEMS devices for detecting sub-nm displacements due to its high sensitivity with shot noise level detection ability [1]. The maximum detectable range is limited to λ/4 of the readout wavelength. In this paper we present 2-wavelength readout method, which offer high sensitivity and long operation range, extending the capabilities of MEMS grating based optical sensors.

Main advantages of the grating based optical readout are that gratings can be micromachined and integrated with single or array of MEMS devices for AFM and ultrasonic sensor applications [1,2], thermo-mechanical IR detector array applications [3], and can serve as comb actuators for Fourier transform spectroscopy applications [4], or other MEMS sensing and actuation applications.

2 EXPERIMENTAL RESULTS

The theory was tested on a MEMS Fourier transform spectrometer shown in Figure 1 [4]. Comb fingers serve the purpose of both actuation and movable diffraction grating. To achieve low-frequency non-resonant mode operation, some tests were conducted by using part of the gratings and a separate moving platform as illustrated in Fig. 1. The device was illuminated using lasers with 632.8, 655.7 nm wavelengths and the reflected first diffraction orders were focused onto two photodetectors.

Sensitivity is given by the intensity change per deflection. The sensitivity for the method is taken as the maximum sensitivity for each wavelength at a given gap. The maximum sensitivity reported with this method is 2×10^{-4} Å/$\text{Hz}^{1/2}$ at 20 KHz, that corresponds to <5pm measurement ability at 20KHz [1]. The maximum sensitivity curve corresponding to the above wavelengths are calculated and shown in Fig. 2.

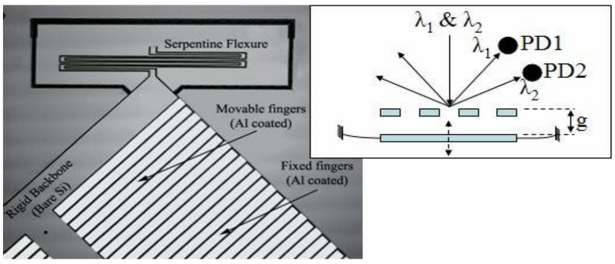

Figure 1. Left: MEMS Spectrometer used in the experiment; Right: side view of setup with moving platform.

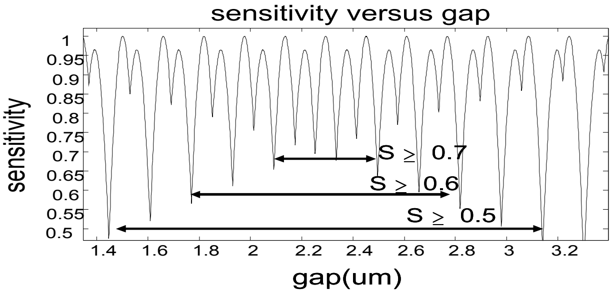

Figure 2. Normalized Sensitivity (S) versus gap.

The sensitivity curve is periodic with D, which is given as:

$$D = \frac{\lambda_1 \lambda_2}{4\left|\lambda_1 - \lambda_2\right|} \qquad (1)$$

For the given wavelength pairs D = 4.6 um. The curve is symmetric around D/2 as seen in Fig. 2. Range versus sensitivity values for one and two wavelength grating interferometry are summarized in Table 1.

Range values may be extended with different sources with smaller wavelength differences. The actuator in Fig. 1 was actuated sinusoidally at 60 Hz. The data obtained from the photodetectors are shown in Fig. 3. Since the gap was modulated sinusoidally, the PD signals are chirped sinusoids.

Table 1. Ranges for different sensitivities for 1 wave readout (633 nm) and 2-wave readout (633nm & 656 nm) Full range gives the period of the sensitivity curve

	S > 0.7	S > 0.6	S > 0.5	Full range
1-wave readout	80 nm	95 nm	105nm	160 nm
2-wave readout	0.4 um	1 um	1.7 um	4.6 um

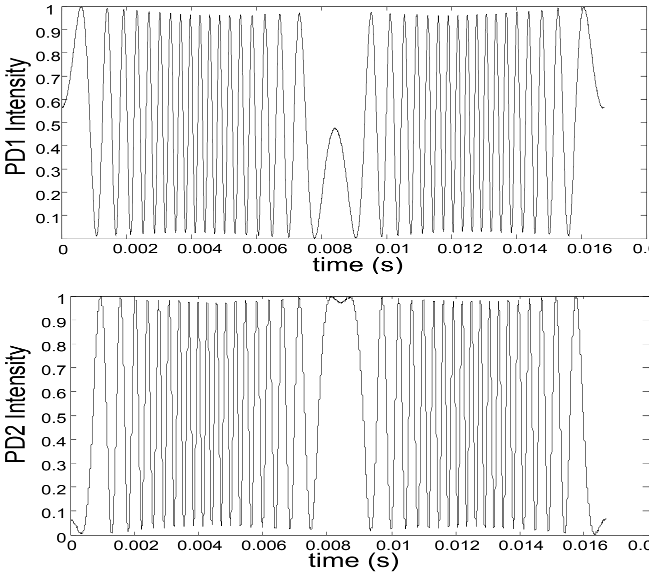

Figure 3. Data collected from two detectors (λ_1= 656 nm in the top figure and λ_2=633 nm in the bottom figure).

The corresponding displacement was calculated to be ±3um using the normalized intensities and is shown in Fig. 4. Each photodiode intensity value corresponds to several possible solutions within the range of operation with a period of half the wavelength. The solution space using PD1 and PD2 signals are compared and the closest possible solution is chosen to find the absolute position in the range. The solution has two gap values calculated from PD1 and PD2 signals, the one with higher sensitivity near the particular operating point should be used for the sensitivity calculations and to determine the absolute position. Similar to single wavelength interferometers, a calibration measurement has to be taken for each sensor to determine the maximum and the minimum intensities corresponding to each photodiode output. When one is dealing with deflections smaller than $\lambda/4$, similar procedure should apply, and the peak intensities determined prior to the experiment would be needed. Laser noise reduction and active calibration can be performed by simultaneously monitoring the 0th order light for each wavelength, which gives the best sensitivity results.

3 APPLICATIONS

The wide range capability enables this technique to be used in dynamic measurements such as the experiment presented here. This technique is able to measure very small deflections at both high frequencies as well as at low frequencies and DC, which is a limitation in Laser Doppler Vibrometer measurement devices that measure velocity.

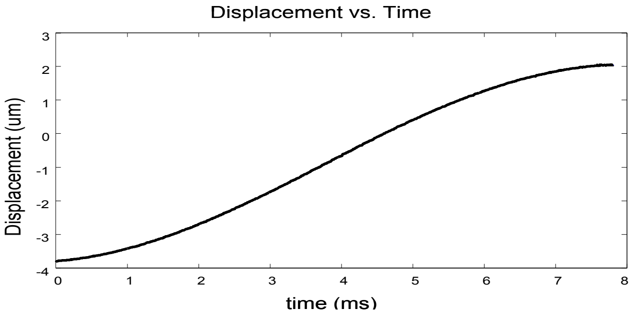

Figure 4. Calculated displacement using PD1 and PD2 data

Another important application is illustrated in Fig. 5. The nanoimaging and biomolecular mechanics measurement devices have shot-noise limited deflection measurement ability with integrated probe and grating interferometer but limited measurement range due to single wave readout [2]. Two-wave readout technique improves the range to several microns, which relaxes requirement on gap fabrication and active control of the gap.

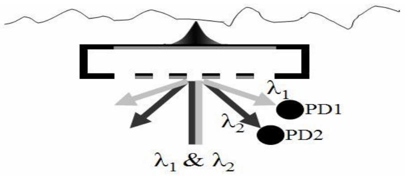

Figure 5. Illustration of AFM application

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