Published in
IEEE/LEOS (Lasers and Electro-Optics Society) International Conference on Optical MEMS, 175-176, 2003
which should be used for any reference to this work

Micro-sized Spectrometer Based on a Lamellar Grating Interferometer

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We present a lamellar grating interferometer (LGI) realized by silicon micro-machining. The LGI is a binary grating with a variable depth. The motion is carried out by an electrostatic comb drive actuator fabricated by silicon-on-insulator (SOI) technology. It is used as Fourier transform spectrometer (FTS). We have measured an optical path difference maximum of 82 µm. The measured resolution of the spectrometer after the phase correction is 6 nm at a wavelength of 633 nm. A preliminary measurement with a xenon arc lamp is shown.

A lamellar grating interferometer (LGI) is a grating that operates in the zeroth order. This particular type of apparatus was invented by Strong [1]. A scheme of the principle is illustrated in Fig. 1a. The LGI is used as FTS, but contrary to the Michelson interferometer that splits wave amplitudes at the beamsplitter, the LGI divides the wavefront. At the grating, the wavefront is divided such that one half of the beam is reflected from the front facets (fixed mirrors in Fig. 1b) and one half from the back facets (mobile mirrors in Fig 1b). The distance *d* between the two series of mirrors determines the optical path difference (OPD = 2*d*) between the two parts of the wave. The enormous advantage of this configuration, compared with a Michelson interferometer, is the absence of a beamsplitter. Indeed, any additional micro-optical component is a limitation in the particular case of micro-sized spectrometers. In general, this type of spectrometer is used for wavelengths larger than 100 μm; below, the tolerances are too tight for most machine shops. Silicon micromachining is the ideal technology to overcome these limitations for shorter wavelengths.

The intensity *I* of the diffraction pattern as a function of the depth *d* of the grating is given by

$$I \propto \left\{ \frac{\sin(\pi a \sin\alpha / 2\lambda)}{\pi a \sin\alpha / 2\lambda} \right\}^2 \left\{ \frac{\sin(N\pi a \sin\alpha / \lambda)}{\sin(\pi a \sin\alpha / \lambda)} \right\}^2 \cos^2\left(\frac{\varphi}{2}\right) , \tag{1}$$

where a is the grating period, α is the diffraction angle, λ is the wavelength, and

$$\varphi = (2\pi d / \lambda)\left[(1 + \cos\alpha) + (a / 2d)\sin\alpha\right] , \tag{2}$$

is the phase delay introduced by the displacement *d*. At the zeroth order of the grating ($\alpha = 0$), Eq. (1) shows that the intensity I_0 varies like a cosine modulation as a function of *d*. The period of the modulation depends on the wavelength. Therefore, the basic equation for Fourier transform spectroscopy applies to the LGI.

The actuator and the grating (composed by the two series of mirrors in Fig. 1b) are fabricated in one etch step by deep dry etching of SOI wafers. For a detailed description of the fabrication process, we refer to the literature [2]. The grating has 12 periods of 90 μm. The scheme of the driving tensions V_0, V_A and V_B is shown in reference [3].

To characterize the performance of our device, we have recorded the zeroth order $I_0(d)$ of the diffraction pattern produced by a collimated HeNe laser on the grating. To get rid of the non-linearity of the driving system, a phase correction is effectuated. The phase correction is described in reference [3]. We have measured an OPD non-linearity Δ_{OPD} of ±0.6 μm for a displacement of 82 μm. Figure 2 shows the spectrum of a He-Ne laser before and after the phase correction. The measured resolution of the spectrometer after the phase correction is 6 nm at a wavelength of 633 nm. To achieve the maximum displacement, we have applied a variable voltage V_0 of ±8.5 V and the constant tensions V_A and V_B were 85 V, respectively -91 V. In addition, measurements with an extended white light source have been carried out. Figure 3 shows the interferogram and the spectrum of a xenon low-pressure arc lamp. In this experiment, the light coming from a multimode fiber is collimated and then focused with a cylindrical lens onto the LGI. The fiber diameter is 50 μm and the focal length of the collimating lens is 16 mm. As the LGI is a symmetrical instrument, only one side of the interferogram needs to be recorded, which results in a higher exploitable OPD.

In conclusion, we have demonstrated the MOEMS application of an old spectroscopic technique. It has been shown that thanks to silicon micro-machining, the concept of LGI can be used in the visible and near-infrared spectral range. In addition, contrary to the Michelson interferometer, no beamsplitter is needed; in our particular case of micro-FTS, this leads to a net improvement in terms of ease of handling.

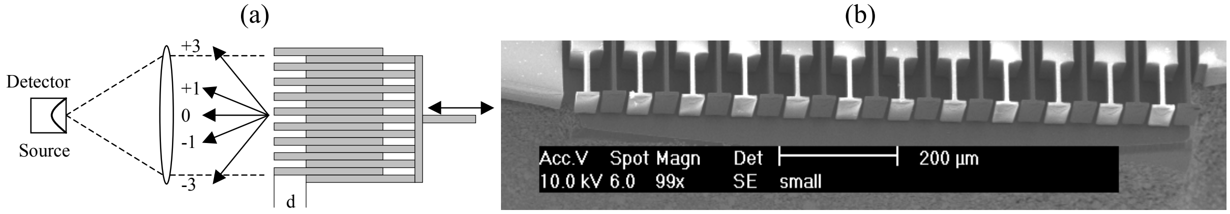

Fig. 1. (a) Principles of a LGI. The modulation of the zeroth order is recorded in function of the depth d *introduced in the grating. (b) SEM photograph of the binary grating. The mobile mirrors are represented in dark and the fixed one are light coloured. The grating period is 90 μm.*

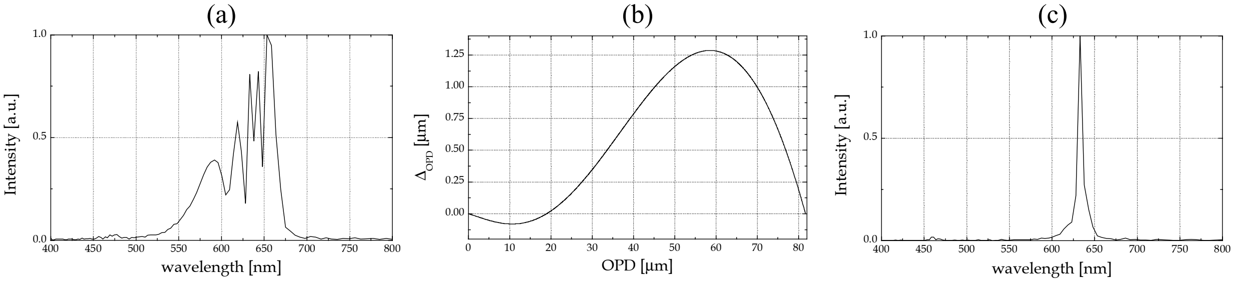

Fig. 2. (a) Spectrum of a He-Ne laser without phase correction, and (c) after phase correction, using Δ_{OPD} shown in (b).

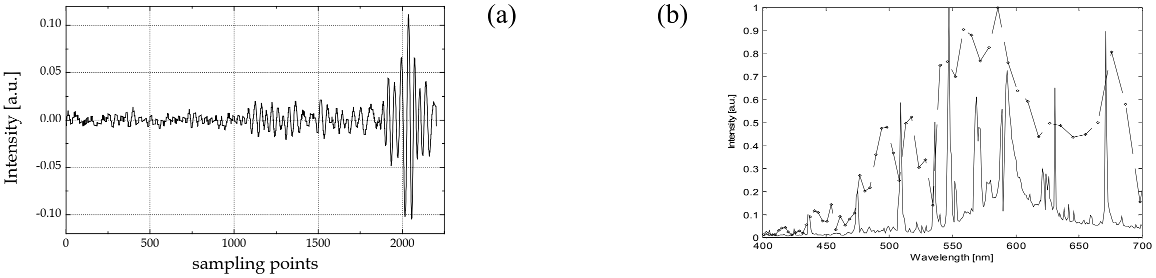

Fig. 3. (a) One-side interferogram of a xenon low-pressure arc lamp. (b) Corresponding spectrum (dashed line). The solid line is the spectrum measured with a 1 nm resolution monochromator.

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