APPLICATIONS OF SHORT COHERENCE INTERFEROMETRY

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Abstract: A measuring principle for the determination of absolute distance and thickness values is proposed. Based on the combination of laser interferometry (Michelson type) and Doppler technique the new developed devices include laser sources showing a short coherence length. This contributions aims to describe some preliminary experiments and to point out some of the main advantages of short coherence interferometry, their non-destructive and non-contact behaviour and the possibilities for self-calibration. The measurement results are mainly independent of the objects´ position and movement. Finally, two relevant problems will illustrate the industrial applicability: the determination of thickness of metal sheets in manu-facturing control and the thickness of transparent objects.

Keywords: Optical metrology, interferometry

1   INTRODUCTION

In commonly used interferometers due to the continuously modulated signal all over the object path, only relative changes of distances are measurable. Therefore, a lot of efforts are done to measure distances absolutely by means of interferometric techniques without any reduction in accu-racy. But still, these measurement techniques are difficult to handle and the devices are quite expen-sive [1,2]. Short coherence interferometry offers a fairly inexpensive alternative - in particular when the requirements are more comparable with triangulation devices than with interferometer applications. In short coherence interferometry, a modulation signal occurs only when both beam paths of the inter-ferometer match within the coherence length of the used light source. Finally, electronic filtering and signal processing yields the so-called Doppler burst whose position is evaluated [3].

Recently, we have used this principle for various industrial applications. Several evaluation criteria yielded i) the optical thickness of transparent glass plates based on the reflections on the front and rear surfaces, ii) the thickness of transparent glass or plastic sides of bottles, iii) the thickness of a opaque metal sheet while it is moving, or iv) the depths of drilled holes. Finally, while the light source is scanned laterally with respect to the sample, the shape of an inspected surfaces can be monitored. In addition in ophthalmology or in dermatology, the principle of short coherence interferometry (here called OCT = optical coherence tomography) allows to assess the thickness of cornea or of subsurface tissue structures [4,5].

Besides an explanation of the basic principle, this contribution emphasises mainly the industrial applicability of short coherence interferometry.

2   MEASURING PRINCIPLE

The optical setup for short coherence interferometry is based on a modified Michelson interferometer, whereat one movable mirror is placed in the reference arm. The uniform move (velocity v) of this mirror causes an intensity modulation of a constant frequency. This effect originates from the Doppler-shifted light from the reference mirror. The Doppler frequency shift f_D is proportional to the scan velocity v.
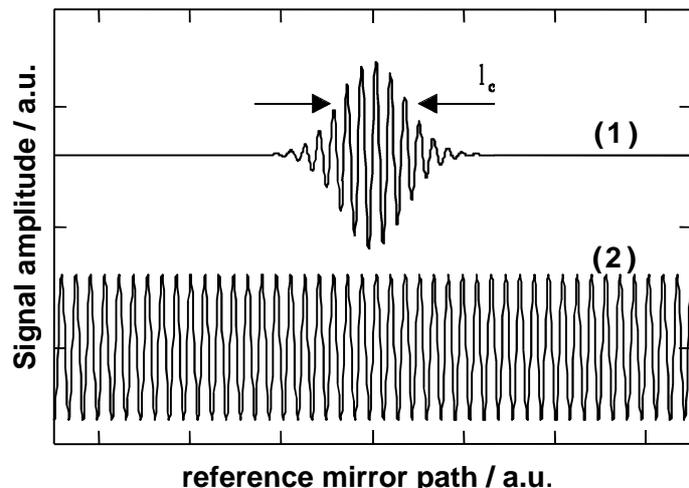
Figure 1. Example for different detector outputs over reference mirror path length, (1) short coher-ence length (e.g. laserdiode underthreshold), (2) long coherence length (e.g. laser)
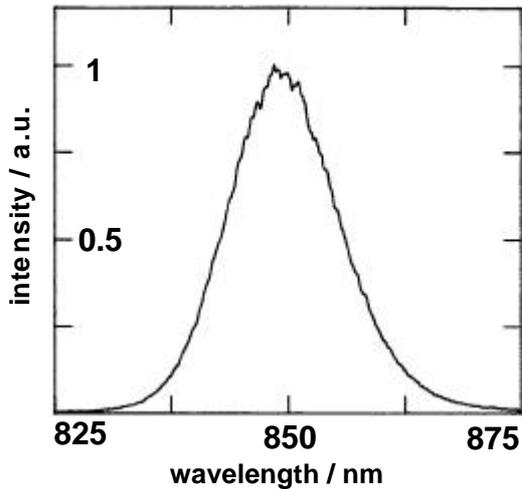
Figure 2. Emission spectrum of a super-luminescence diode

$$f_D = 2\frac{v}{\lambda} \tag{1}$$

With the velocity of the reference mirror in the range from mm/s to cm/s the Doppler frequency shift is up to several kHz. If we assume a Gaussian line shape of the emitted spectrum, the FWHM (full width half magnitude) of the coherence envelope (l_C) is related to the FWHM wavelength bandwidth ($\Delta\lambda$) of the source by:

$$l_c = \ln(2)\frac{2}{\pi}\frac{\lambda^2}{\Delta\lambda} \tag{2}$$

Due to the limited wavelength bandwidth ($\Delta\lambda$) of a HeNe laser the coherence length (l_C) is typically up to several meters (figure 1 below). Out of the continuous interference signal within the limited mirror movement over this path length, an absolute determination of distances in the range of micrometers is impossible. Instead of a HeNe laser other light sources with broader emission spectra can be used. Then, due to their short coherence length l_C a modulation signal in a Michelson interferometer setup will only be detected while the different path lengths of the two interfering beams are equal within a path length of l_C. And, out of a DC background signal a so-called Doppler burst appears (see figure 1 above). Now it is possible to determine the position of the object mirror with an accuracy of $l_C/2$. This accuracy depends mostly on the coherence length of the used light source. Figure 2 shows the emission spectrum of a super luminescence diode suitable for the application in short coherence interferometry. According to equation 2 the light source has a coherence length of about 25 µm.

3 EXPERIMENTS AND RESULTS

3.1 Thickness of opaque media

Figure 3 shows a device which is feasible to measure the thickness of metal films, sheets or plates, that are commonly opaque for visible light. This instrument consists of two Michelson interferometers wherein two mirrors are replaced by the two surfaces of the object. The output beam of the first interferometer serves as the input of the second one. Without an object a self-calibration measurement can be done where the position of the movable mirror for zero path length difference of path 1=(a1+d+a2+a+b+a+a1+d+a2) and path 2=(2*b1+a+b+a+2*b2) can be determined. With the object of the thickness d in place the path length difference is zero for path 1=(2*a1+a+b+a+2*a2) and path 2=(2*b1+a+b+a+2*b2). In comparison to the calibration measurement (z=0) the movable mirror is now at the position (z=d). Obviously, the measurement is independent of the object's position.

Figure 4 shows the result on 0.2 mm thick metal sheet. The signal which is proportional to the intensity is plotted as a function of time which is proportional to the way of the moving mirror for a constant velocity. After a
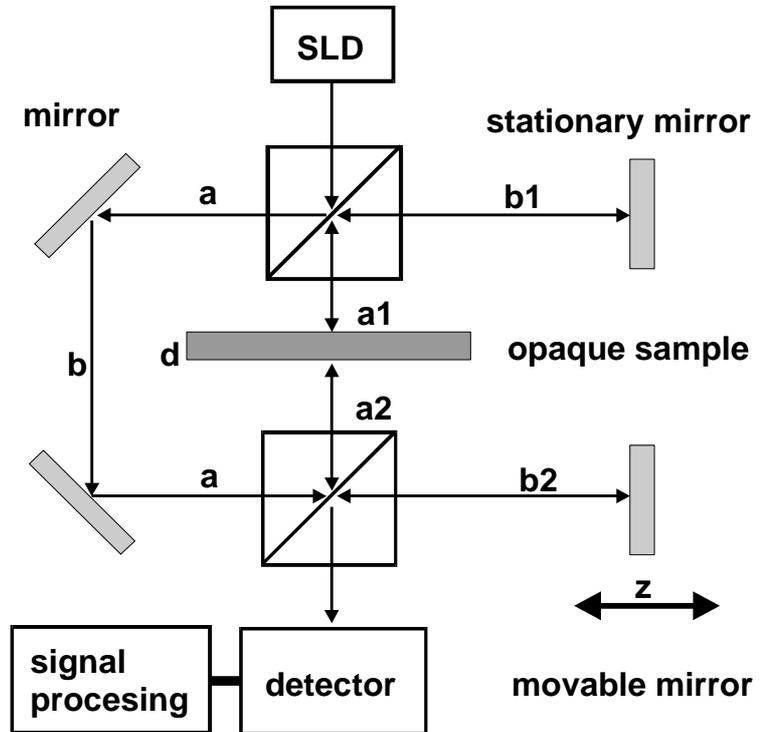

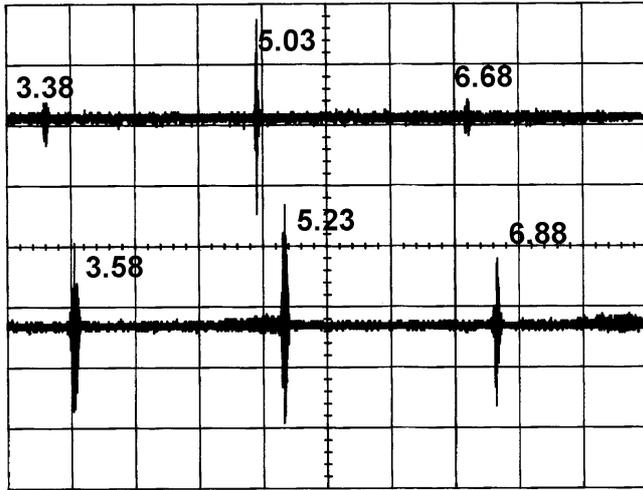**Figure 3.** Setup for thickness measurement of opaque samples

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Figure 4. Measurement of a 0.2 mm thick metal sheet

calibration measurement (signal below) where the zero point has been determined, the measurement with the metal sheet was done (signal above). The distance between the burst positions in both signals is the sheet's thickness. The measurement is not influenced by the environment conditions like temperature or humidity, because the two beams follow almost the same path. Furthermore, the measurement is independent of temperature and position of the sample, because these parameters do not contribute to the Doppler-burst signals. Investigations have shown that on smooth surfaces no problems occur that may be caused by the specimen's movement. At rough surfaces the velocity of the sample sho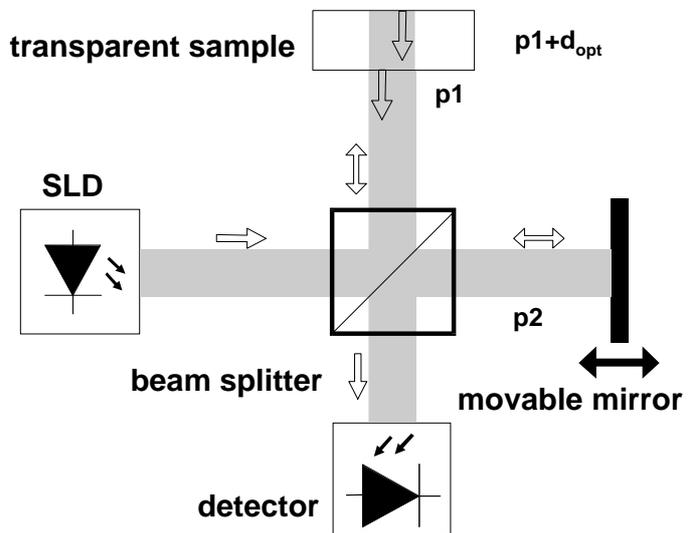uld be lower than the velocity of the movable mirror. The contactless manner of this device has advantages for sensitive surfaces and enables fast measurements with an accuracy in the µm range. There is no demand for special optics and electronics. Thus, a low-cost integration into production lines may be allowed for manufacturing control purposes.

3.2 Setup for transparent samples

Figure 5 shows schematically a second device especially designed to determine the thickness of light transparent specimens. Whenever a steplike change of the refractive indices happens at the interfaces between environment and sample, a part of the impinging beam is reflected from the front and the backside of the measurand. This leads to two signals which allow to determine the absolute thickness, taking into account the refractive indices n of the media that is passed by the measuring beam. The first

Figure 5. Setup to measure the thickness of transparent samples

signal appears when the beam paths p1 and p2 are equal, the second one when $p2=p1+d_{opt}$ where d_{opt} is the optical thickness ($d_{opt}=d*n_i$) of the sample. Exemplarily, figure 6 illustrates the detector output signal after electronic filtering and signal processing. In this case the measurand was an empty transparent plastic bottle. Also, the thickness measurement of filled bottles is possible, if there is enough light reflected from the rear surface. Figure 7 shows a recently developed prototype for demonstration purposes.

Figure 6. Doppler bursts as received from two reflective surfaces

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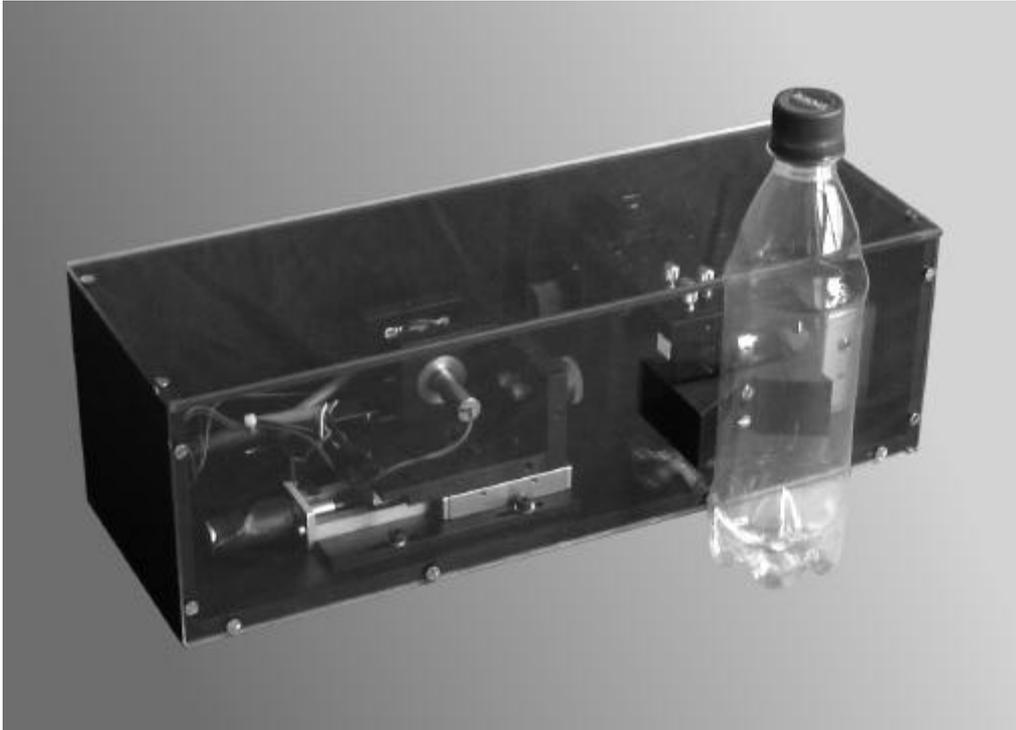
Figure 7. Prototype to measure the thickness of light transparent objects

Also the thickness of semiconductor wafers which are transparent for infrared radiation could also be investigated in this way. For this, light sources emitting in the infrared range have been used [7].

4   CONCLUSIONS

The proposed interferometric devices use light sources showing short coherence length. Momentarily, the achievable measurement uncertainty is mainly restricted to the coherence length of about 10 µm. Some additional measurement errors are caused by the mechanics and the recording of the detector signals. Up to now, we achieved a repeatability of about 3 µm. In transparent media problems in thickness measurement may result from unknown refractive indices of the inspected media. But nevertheless, the constancy of glass or plastic bottle sides could be measured with a sufficiently good reproducibility and fairly satisfying resolution. Altogether, short coherence interferometry is an alternative method for absolute distance and thickness measurements. In the near future, the data acquisition time will be increased and some further aspects for shape measurements will be evaluated.

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