# DUV-Shearing Interferometer with reduced spatial coherence

Irina Harder, Johannes Schwider, Norbert Lindlein

*Institute of Optics, Information and Photonics, University Erlangen*
*Staudtstr. 7/B2, 91058 Erlangen*

mailto:iharder@optik.uni-erlangen.de

A DUV lateral shearing interferometer based on two Ronchi phase gratings is presented. The whole setup is working with an ArF excimer laser at λ=193nm. As this light source always comes with a reduced temporal and spatial degree of coherence special measure has to be taken to increase the contrast of the desired interferometric fringes.

## 1 Introduction

For several years now premature aging of fused silica due to DUV exposure is known. The damage results mainly in compaction or rarefaction effects [1]. Although this leads only to a small change of the refractive index, it contributes nevertheless to the aberrations of a lithographic objective since long path lengths in fused silica are quite common.

For the measurement of this effect long cubes of fused silica are exposed for several months to a DUV laser beam of 0.2mJ/cm²-10mJ/cm² and measured interferometrically at a wavelength of λ=633nm (HeNe-Laser) [2]. However, the interesting wavelength domain for the application remains the DUV region because the working wavelengths of the lithography systems are situated there.

We built a Ronchi shearing interferometer based on a ArF excimer laser with a working wavelength λ=193nm. For a first test of the setup small samples of fused silica with a diameter of 1" and a thickness of 5mm are used. The samples were structured by reactive ion etching so that a flat step on the surface in the centre of the sample is achieved. The diameter of the structure is 2mm and therefore has a similar size like the disturbance due to the exposing beam.

## 2 Lateral shearing with Ronchi phase gratings

Basically the lateral shearing interferometry uses two wave front copies which are laterally sheared one to another. Interference fringes are only observed in the overlap region of the two shifted copies. Then the measured wave front *ΔW* is the difference of the two sheared wave front copies $\phi(x+½\Delta s,y)$ and $\phi(x-½\Delta s,y)$ if the shear was applied in x-direction. For compaction measurement one has to deal with local disturbances on an undisturbed area. So, a total separation of the two sheared disturbances can be achieved. In this case the wave front error can directly be seen in the unwrapped image of the measured wave front with both positive and negative sign, with respect to the undisturbed wave front.

Here, the amplitude division and the shearing is done by two Ronchi phase gratings (see Fig. 1). The first grating acts as the beam splitter. As a Ronchi grating is defined to have a duty cycle of 1:1 all even orders are suppressed. Apart from the zeroth order only the two first diffraction orders receive maximum intensity. To increase the efficiency of the first orders and suppress also the zeroth order a phase-only Ronchi grating is used.

An identical second Ronchi grating is parallely placed behind the first grating and simply parallelizes the two first orders [3] by introducing similar diffraction angles. Obviously the spacing between the two Ronchi gratings results in a lateral displacement of the two first orders. The shear is given by the distance between the gratings *a* and the diffraction angle $\alpha$:

$$\Delta s = 2a\tan(\alpha) \approx 2a\frac{\lambda}{p}, \qquad (1)$$

where p is the period of the grating.

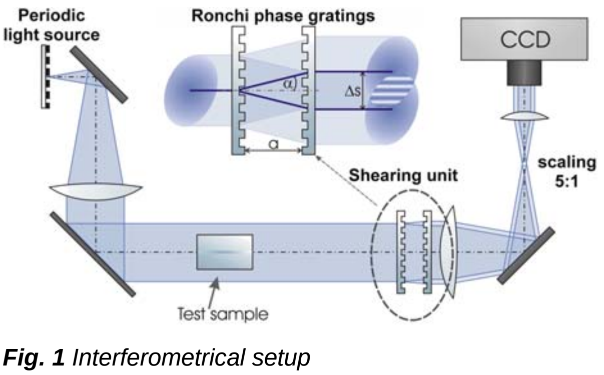


***Fig. 1*** *Interferometrical setup*

## 3 Interferometry with partial coherence

To achieve a total separation of the disturbance on the two wave front copies, shears of several mm with respect to the object plane are needed. This leads to high requirements on the coherence of the used light source. In comparison to a laser light source like the HeNe-Laser, which is normally used for interferometric measurements the excimer laser is a light source with both poor temporal and poor spatial coherence.

As this shearing setup is a totally symmetric common path interferometer for perpendicular impinging waves the temporal coherence has no effect on the visibility of the interference fringes.

The partially spatial coherence limits the maximum possible shear since the shear between interfering wave front points has to be smaller than the lateral coherence area. The variation of the contrast of two beam interference depending on the coherence is expressed by the complex degree of coherence. Due to the Van-Cittert-Zernike theorem the complex degree of coherence of a light source is given as the Fourier transform of the intensity distribution of the light source. If the source has a periodic intensity distribution instead of a homogeneous one the complex degree of coherence also shows a periodic curve shape (Fig. 2). So the contrast returns for destined spacing of the interfering wave front points [4].

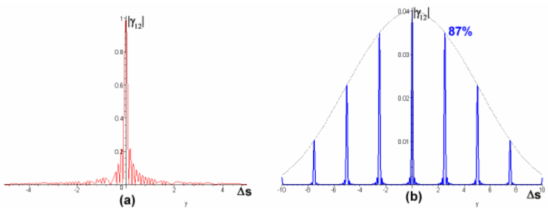


***Fig. 2*** *Absolute value of the complex degree of coherence of a rectangular (a) and a periodic (b) light source with the same diameter.*

## 4 Experimental setup

In the experimental setup the periodic light source is created by an opaque grating with a duty cycle of 1:4 and a period of $p$=50µm (see Fig. 1). This leads to a theoretically possible contrast of 87%. The contrast will return for a shear of $\Delta s$=5.02mm in the plane of the sample under test. The light is collimated by a best form lens made of fused silica with a focal length of $f$=650mm. The sample is then imaged by a telescopic setup onto the CCD (Quantix 1401E, Photometrics). The shearing unit are two Ronchi phase gratings with a period of 5µm and a height of the surface structure of 170nm made of fused silica which are placed in front of the first imaging lens. As the diffraction angle is 2.2°, the shearing distance must be 65mm to achieve a shear $\Delta s$=5.06mm. For phase shifting purposes the first grating is mounted on a piezo which moves perpendicular to the grooves of the grating.

## 5 First results

In Fig. 3a the unwrapped phase of the structured fused silica sample is shown. The desired phase step nearly vanishes due to the wave front errors of the sample itself and the optical setup. To achieve a useful sensitivity for small steps those errors have to be reduced. To get rid of the unwanted wave front errors the sample under test was already measured before the structuring. This measurement was afterwards subtracted from the measurement of the structured sample Fig. 3a. The resulting phase profile is shown in Fig. 3b. The background is now smaller than the desired phase steps if the repositioning of the sample after structuring is done well. The double optical path difference of the disturbed area with respect to the undisturbed area can now be measured by determining the difference between the two sheared disturbances. For this sample we measured a height of 2$OPD$=0.13$\lambda$. This complies to a step height of 22nm.

Unfortunately the setup still suffers from instabilities of the light source which can be seen by looking at the statistical values of Fig. 3b. To stabilize the setup and so increase the certainty of the measurement some efforts have still to be made.

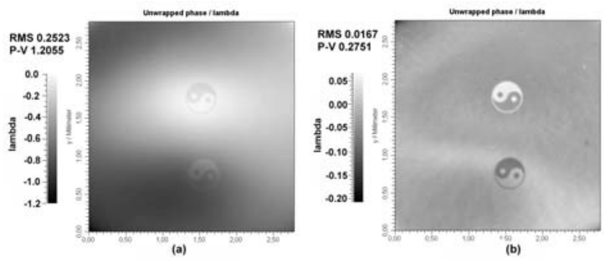


***Fig. 3*** *First measurement of a small phase step. The original measurement (a) and the result after subtracting the empty sample measurement (b). The resulting phase difference between the sheared phase step images was 2*OPD=0.13$\lambda$*

## References

[1] Schenker R. et al: „Deep ultraviolet damage of fused silica “, *J. Vac. Sci. Technol. B 12(6)*, 3275-3279 (1994)

[2] Liberman V. et al: „Excimer-laser-induce densification of fused silica: laser-fluence and material-grade effects on scaling law“,J. Non-Crystalline Solids 244, 159-171 (1999)

[3] Schreiber H. et al: „A lateral shearing Interferometer based on two Ronchi Gratings in series“, *Appl. Opt. 36(22)*, 5321*ff* (1997)

[4] Wyant J.C.: „White light extended source shearing interferometer”, *Appl. Opt.13*, 200*ff* (1974)