Application Report:

PHASE SHIFT MASK MEASUREMENTS WITH EXCIMER LASERS

IndyStar

Heavy Duty Performance -
Highest Efficiency

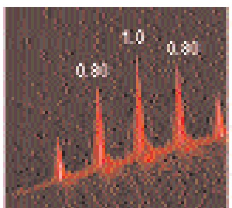
Why Excimer Laser?
• Small Wavelength (193nm)
• High Peak Power

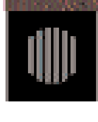
Why IndyStar?
• High Repetition Rate (up to 1000Hz)
• 90% Duty Cycle (at 1000Hz)
• SEMI Certified Process Devices
• Unmatched Energy Stability (s < 3%)
• Easy External Communication (RS 232)
• Strong Symmetric Beam Profile

Your Benefits:
-> Excellent Results
-> Economical
-> Highly Versatile
-> Compact Size

The trend toward smaller feature sizes in microlithography requires not only a shift to shorter wavelength, but also the use of special techniques, so called Resolution Enhancement Techniques.

A very successful technique is the application of Phase Shift Masks (PSM) in addition to the common Amplitude Mask. The PSM introduces a complex amplitude information and a phase shift in parts of the wavelength in use. In this way the critical dimension of the lithographic process can be improved because the complex amplitude has also negative values which provides a much better definition for the intensity value zero. However, one difficult issue is the reliable measurement of phase shifts created by the PSM in the deep UV. This is due to the lack of suitable and simple interferometric devices in the deep UV. In this application report a deep UV interferometer based on phase gratings is presented.





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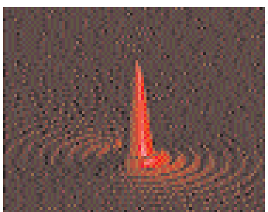
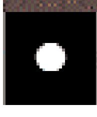
Contrast: 0.80





Comparison with an "equal area" source

Figure 1:
Complex degree of coherence designed for large shears

Principles of PSM measurement

By combining two Ronchi-phase gratings, placed in the imaging light path of a microscope working in transmission mode, it is possible to generate two laterally sheared wave fronts which carry the phase information of the object of interest. The introduced shear depends on the distance between the two Ronchi-phase gratings.

A five-phase algorithm can be used to analyze the fringe pattern generated as a function of the lateral shift between the two gratings. Information about the phase shift of the object is thus obtained.

To introduce large shears, a complex coherence has to be prepared. This is done by the use of a structured light source, a technique which reduces unwanted interferences and allows for a high contrast ratio (>0.8) combined with minimum light loss (see Fig. 1). Under these conditions, the phase step introduced by a PSM structure can be measured with a high degree of accuracy.

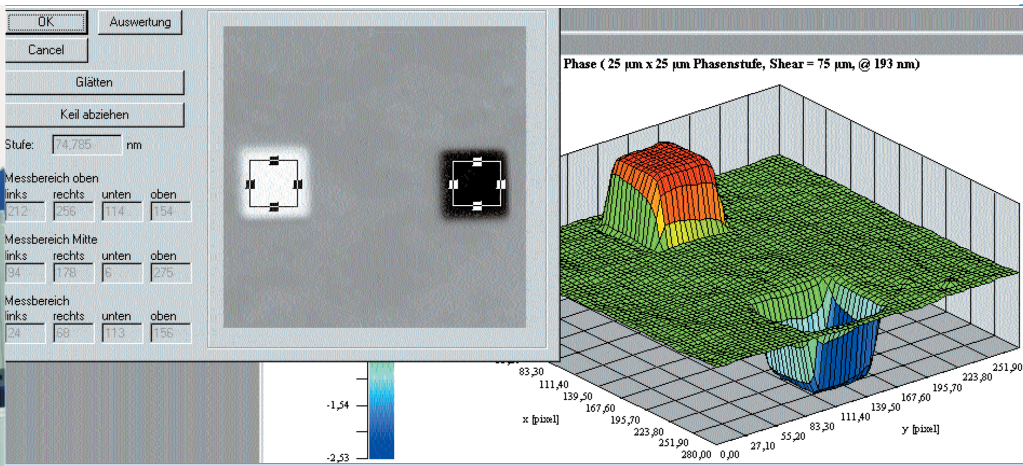


Fig 2: Phase profile of a 25 µm by 25 µm phase step in a shearing representation measured at 193 nm.

Design Considerations of the Interferometer and Light Source

The stability of the interferometer is critical for measurement accuracy, especially if short wavelengths are to be used.

For instance a phase shift between the interfering waves resulting from a 1 nm feature leads to a change in intensity of only 1.65% at 193 nm. In order to map features with sub-nanometer dimensions, changes in intensity on the order of 1% must be accurately measurable.

The stability of the laser source is the overriding design feature of a sufficiently accurate interferometer. When measuring the phase steps of the mask, sub-nanometer accuracy is necessary in a state-of-the-art lithographic process.

Without an extremely stable light source this is not possible. Low shot-to-shot noise and high long-term stability (over a period of hours) in both continuous and burst modes are required for high performance interferometry at 193 nm. Another parameter which must be optimized is the beam profile. An asymmetric beam profile results in poorly defined coherence in the object plane of the interference microscope.

A homogeneous beam profile is a key to data that can be interpreted meaningfully. Furthermore, the stochastic noise in the CCD detector can be quite significant.

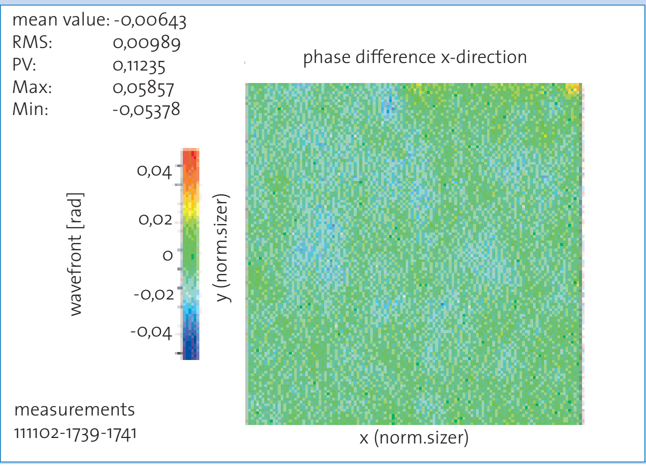
Only with a high repetition-rate excimer laser can sufficient averaging be carried out to obtain acceptable signal-to-noise ratios in the phase measurements. Wind currents and temperature fluctuations in the laboratory preclude the use of low repetition-rate excimer lasers, which, in any event, would unnecessarily increase the sampling time.

A final technical requirement of the system is the need for reliable synchronization between the CCD and the laser through the software driving the device. Precisely the same number of laser pulses must be averaged for each CCD frame to optimize the data. A suitable trigger input to the laser (typically TTL) must be available.

A diffractive shearing interferometer based on a Coherent IndyStar excimer laser implements a stable common-path design, using only a minimum number of additional optical components compared to a more traditional Mask Qualification system. Thus the difficulties associated with stability requirements and material properties in the deep UV, such as absorption and scattering losses, are overcome.

Coherent has carefully optimized its IndyStar ArF excimer laser to meet the demanding requirements of PSM applications. Sophisticated design technologies including Solid State Switching and Corona Preionization of the discharge ensure long term stability, excellent shot-to-shot noise characteristics, and a homogeneous beam profile in the high repetition rate excimer laser. Coherents engineers have implemented an easy-to-use triggering protocol to allow appropriate synchronization of all components of the device.

Fig 3: Reproducibility of phase measurements
is l/650 (0.3nm at 193 nm)



Experimental Results

To determine the efficacy of a Coherent IndyStar in PSM applications, phase shift measurements were performed using various phase shifting configurations.

The reproducibility of the diffractive shearing interference microscope was found to be l/650 RMS, or 0.3 nm at l = 193 nm (see Fig. 3).

The interferometer was extremely stable and easy to use. The phase step introduced by binary phase shift structures can be extracted by the analysis software, with or without user input in various ways (see Fig. 2). A complex coherence was implemented to allow a high interference contrast ratio of >0.8 even at large shears. This was done by the use of a stripe geometry of the light source, realised by a set of amplitude gratings varying in the grating period to work at different shears.

We have demonstrated a stable and accurate diffractive shearing interference microscope for use at l = 193 nm using a Coherent IndyStar ArF high repetition-rate excimer laser. We also have demonstrated a reproducibility of 0.3 nm in phase shift mask measurements. Extension of this technique to wavelengths as short as 157 nm is currently being undertaken.

Our Customer References:

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