

# Ultra high resolution DUV water immersion microscope objective

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In the context of the introduction of DUV immersion lithography also DUV immersion microscopy, at least for mask metrology, is by now accepted in the semiconductor industry. In the paper a DUV 200x water immersion microscope objective with  $NA = 1.25$  for 248 nm wavelength and a half pitch Rayleigh resolution of 60 nm is discussed, covering the aspects of optical design, tolerancing, mounting techniques as well as applications.

## 1 Introduction

In the semiconductor industry DUV microscopy at 248 nm wavelength is well established for wafer inspection and mask metrology. The next step in wavelength to 193 nm for higher resolution is severely hindered by a lot of technical difficulties and a very restricted usability for only small niche applications.

With 248 nm water immersion microscopy about the same resolution can be achieved as with 193 nm non-immersion optics. The big advantage, however, is that the whole optical infrastructure of an existing 248 nm tool can be kept unchanged except that a dedicated microscope objective is needed as well as water application and removal to and from the sample.

The DUV 200x/1.25/248nm WI water immersion objective described in this paper was developed primarily to be used for mask line width ("critical dimension", CD) metrology.

## 2 DUV 248 nm WI objective

Taking manufacturing tolerances, costs and production performance into account, it is wise to restrict to a dry- $NA = 0.90$  as an upper limit for a high resolution DUV objective. With  $n_{248} = 1.3784$  for water this results in an immersion- $NA$  of about 1.25 which in turn provides a Rayleigh half pitch resolution of 60 nm, even slightly superior to that of a 193 nm  $NA = 0.90$  objective. In addition to this primary specification on  $NA$  and resolution the following very challenging requirements were put on the optical system design:

- to be used with normal visible light (VIS) objectives on the same microscope turret
- magnification 200x (focal length 1 mm)
- free working distance  $\geq 0.25$  mm

- finite bandwidth design  $248 \pm 8$  nm for HgXe arc lamp illumination
- parfocal spherical aberration correction also at 903 nm to utilize an existing laser auto-focus module
- no cemented lens elements
- no lens mounting by adhesives
- tolerance sensitivity compliant with Strehl ratio  $\geq 0.96$  ( $\leq \lambda/30$  RMS-OPD) production performance

The magnification of 200x is somewhat misleading. Including a 2x post-magnification to the CCD camera, the total magnification on a 19" monitor is actually  $>20\,000x!$  Fig. 1 shows the lens cross section of the 200x/1.25/248nm WI objective. It consists of 19 single lens elements made from fused silica and calcium fluoride within a total length from the first to the last lens surface of about 72 mm. Even though the objective is considerably longer than normal microscope objectives, it is still rather slim and with extension tubes on the VIS objectives it fits to the same turret.

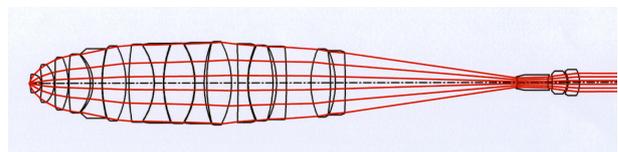
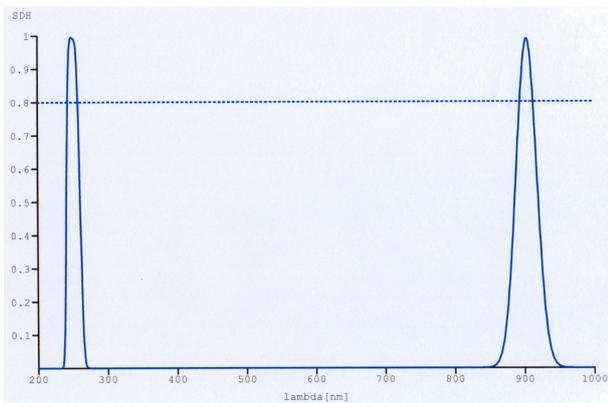


Fig. 1 Cross section DUV 200x/1.25/248 nm WI

Fig. 2 shows by Strehl ratio versus wavelength how perfectly the 248 nm finite bandwidth and parfocal 903 nm correction could be achieved.

The lens mounting in "airspace technology", i.e. without cemented lens elements calls for extremely tight air space tolerances of about  $\pm 2$   $\mu\text{m}$  and for this kind of objectives was for the first

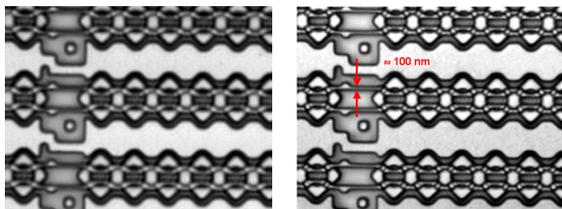
time successfully achieved with the dry objective DUV 150x/0.90/248 nm AT in 2001. In the new objective even no adhesives are used for fitting the lens elements into their mechanical cells. First attempts with classical border crimping failed because asymmetric mechanical stress on the lens elements could not be reduced below an acceptable level. The solution turned out to be fixing the lens elements by retainer rings. This method is considered to be a rather crude one and not applicable for high precision optics. The key to success was to apply elastic shims made from a DUV resistant material between the lens elements and the retainer rings.



**Fig. 2** Dual bandwidth design  $248 \pm 8$  nm + 903 nm (Strehl ratio versus wavelength)

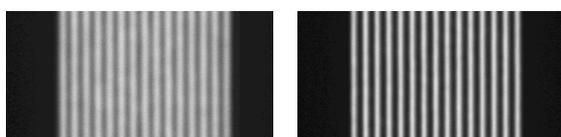
### 3 Optical performance

Figures 3 and 4 show the gain in image performance of the immersion objective. On the left is the image with a 150x/0.90/248nm objective scaled to the same size as that on the right taken with the new water immersion objective:



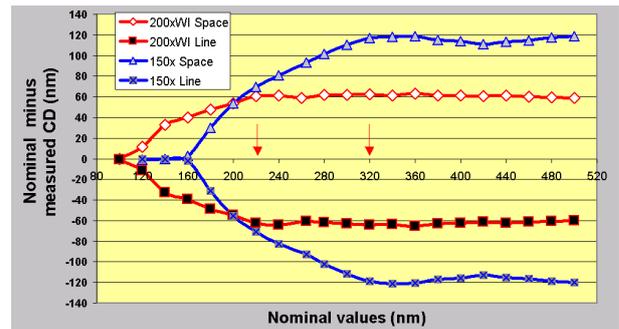
**Fig. 3** Wafer pattern: "dry" versus "immersion" image

Fig. 4 shows an analogous comparison for a chrome-on-quartz test mask with 125 nm half pitch 1:1 lines & spaces:



**Fig. 4** L&S on mask: "dry" versus "immersion" image  
As mentioned above, the DUV WI objective was developed primarily for line width (CD) measure-

ments on masks. One key performance parameter for this is the CD-linearity range, i.e. the smallest line width down to which the nominal and measured CD figures show a linear relationship. Fig. 5 shows the deviation of the measured from the nominal CD values for lines (and spaces) of width 500 nm down to 90 nm. With the DUV WI objective the linearity range is extended to about 220 nm as compared to about 320 nm for the dry objective:



**Fig. 5** Improvement of CD Linearity: from  $\approx 320$  nm ( $NA = 0.90$ ) (blue) to  $\approx 220$  nm (red)

### 4 Outlook

In the history of the development of microscope objectives towards higher resolution by utilizing immersion and going to shorter wavelengths, the  $NA = 1.25$  water immersion objective for 248 nm wavelength with its 60 nm half pitch resolution is most likely the end of the line as seen from a more general commercial point of view. Exceptions most likely are not going to disprove this statement. For example, there are water immersion microscope objectives for 193 nm wavelength with  $NA = 1.05$  and 1.15 available [1], however, they do not fit in a mix and match mode with VIS and UV objectives on a "regular" microscope so that the applications are very limited. This is even more so with EUV microscopes working at 13.4 nm wavelength. The applicability of those is very questionable - except possibly for one single application: EUV mask inspection. With any new attempts and efforts to increase optical resolution one has to keep in mind the inherent resolution advantage of electron microscopy!

### 5 Acknowledgment

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[1] Tropel AquaCAT, [www.tropel.com](http://www.tropel.com)