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Microscope Objectives for Semiconductor Metrology: Technology Driver for the Mounting Technology of Optical High Performance Systems with Small Diameters.

Abstract

This paper presents current and future requirements of the lens mounting technology for optical high performance systems with small diameters. These systems are mechanically characterized by an outer diameter between 20 and 80 mm, which is common for standard microscope objectives. An optical characterization is given by a high numerical aperture and an optical design for DUV/VUV applications. The optical performance with respect to the strehl ratio is well in excess of the diffraction limit (>95%).
Quality inspection is an essential element for commercial success in semiconductor industry. These types of optical systems are used in semiconductor metrology for non destructive inspections systems and occupy a central position in the semiconductor production line. The continuous shrinking feature sizes of the semiconductor chips requires the steady increasing resolution of all inspection tools. The requirements on optical system design and production are also increasing. With today's technologies these requirements can even be achieved with great expenditure. Significant improvements along the whole production process are necessary to meet future needs. The lens mounting is one major task in this process. Forward looking lens mounting technologies are required to be much more stress relieved and position stable then other current technologies.

Hence, for the methodical approach of the "Ilmenau design theory" it is necessary to propagate these requirements to generate proposals for novel solutions.

Background

With the introduction of immersion lithography in combination with high numerical apertures and the use of 193 nm systems, the lithography world continues on its path to even more smaller features. The shrinking feature size requires inspection tools with increasing resolution. Contactless and non-destructive optical inspection systems are particularly suitable for this applications.
It is impossible to achieve an apochromatic correction of a refractive DUV objective, typically made of silica and CaF_2. For typical broad-band objectives operating within the visible spectrum an apochromatic colour correction is state of the art. In the visible spectrum cemented lens doublets and triplets are typically used for the

correction. However, cemented lens doublets and triplets are not applicable for DUV/VUV applications, because the cement can not withstand the high photon energies. In such systems the optical design uses air spaced doublets and triplets to achieve the colour correction. That causes extremely high demands on form and positioning errors. The following production tolerances for a single lens are stated below [1]:

- radius error of spherical lens surface $\Delta R < \lambda/2$
- thickness error < 5 µm
- peak-to-valley error of surface geometry (deviation from the best fitting sphere) $OPD_{pv} < \lambda/10$
- root-mean-square surface roughness $R_q < 0{,}5$ nm.

OPD is the optical path difference of the corresponding real wave front with respect to the best fitting plane in units of λ.

According to the literature[2] the mounting tolerances are given by:

- lateral positioning error of the lens axis with respect to the optical axis of the system < 2 µm
- tilt of the lens axis to the optical axis of the system < 0,3 arcmin
- longitudinal positioning error of the individual lens < 2 µm

The mounting tolerance on its own is not sufficient to reach the system performance specification. However, even with great expense, smaller tolerances for single elements are not possible [1]. Hence, different adjustment elements have to be used to reach the system performance with regard to the strehl ratio in excess of 98%.

Spotligth on selected novelties

For systematic examinations with mounting technology it is necessary to structure the topic in reasonable subtasks. A possible structure is the schematic production process for optical high performance systems given in fig. 1.

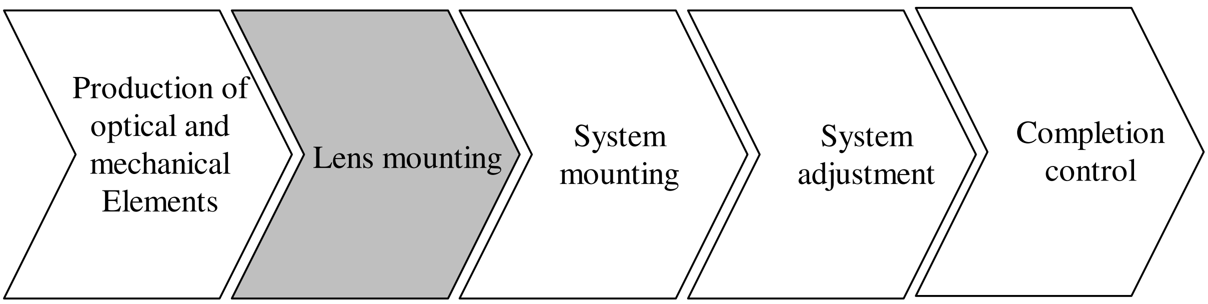

Figure 1: Schematic production process for optical high performance systems

This paper is about future demands in the subtask lens mounting.

The task lens mounting is to be engaged with the interface between an optical element and a mechanical element. The task is not to mistake with the task system mounting that is to be engaged with the interface between already in mechanical elements mounted optical elements. This interface is used to sub assemblies or assemblies like an objective. Fig 2. illustrates this particular case.

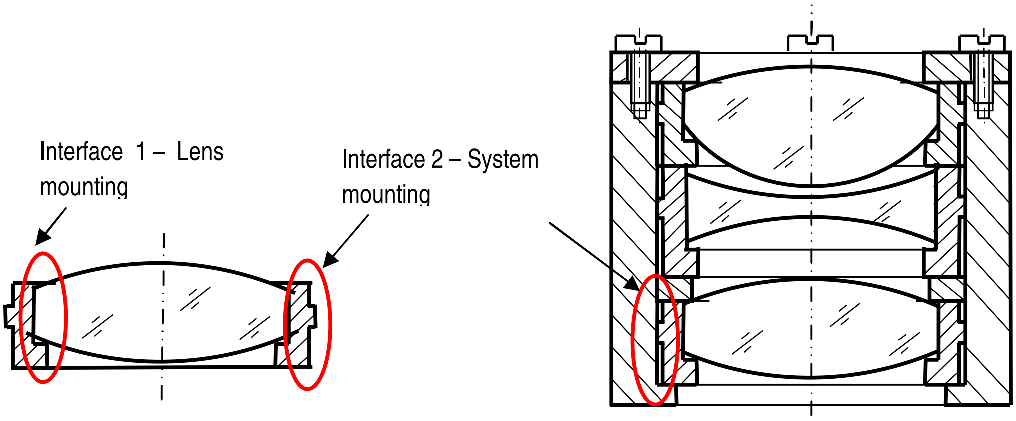

Figure 2: Different interfaces of mounted optics

Lens mounting

This section is refers to the necessary properties of the lens mounting interface and the verification of these properties.
[1] [2] gives requirements for the surface error of optical elements, for the relative position of the optical elements to each other, and to a superior reference, respectively.
These requirements have to be achieved precisely in the related production process. Furthermore, there is a need to avoid any deviations during the following production steps and over the systems lifetime with its different influencing variables. Thus, for the mounting technology a stress relieved and position stable lens mounting interface is necessary.

The stress relieved lens mounting interface has to achieve a well defined position of the optical element without using forces that may affect its function. This claim is valid over the typical systems lifetime period of ten years and under environmental effects. The environmental effects are given below. There are different options to characterize a stress relieved mounting interface. One is the characterization by the optical surface error. In order to get a characterizing dimension it is possible to separate the error budget of the optical element into the part of the production process and the part of the following process steps, especially for the lens mounting and the lens mounting interface. A given surface error of $\lambda / 20$ in units of the wavelength results at a working wavelength of $\lambda = 633$ nm in a tolerance of 32 nm. This tolerance can be realised with great expense in the production process. Consequently, at most ¼ of this tolerance can be taken for the lens mounting. Hence, it can be assumed, that the optical surface error given by mechanical stress should be less than 8 nm. This requirement can easily be verified by interferometric measurements, generally done in the production process of optical high end elements, see [1].

Another approach is given by the measurement of the optical retardation as equivalent to the mechanical stress. For this application polarimeters are used, operating on basis of a stress birefringence measurement. For semiconductor metrology solutions, like mask evaluation, the stress birefringence of a single optical element should be less than 1 nm. Metrology technologies, i.e. aerial imaging [3], capture so called "real world mask effects" such as polarization, diffraction and rigorous 3D mask-effects. Especially for measuring polarization effects the optical system should not be generate additional effects. In practice this claim shows a good correlation to the characterization by a surface error (see above). Commercial available polarimeters with a reproducibility of the optical retardation measurement +/- 0,1 nm are qualified for the verification of lens mounting interfaces.

The position stable lens mounting interface has to achieve a well defined position of the optical element without any relative movement to the holder during the whole lifetime and under environmental effects. To characterize this claim we give the following requirements:

- lateral movement of the optical element with respect to the holder < 50 nm
- longitudinal movement of the optical element with respect to the holder < 200 nm
- tilt of the optical elements optical axis with respect to the holder < 0,1 arcsec.

Temperature change, UV radiation, humidity, vibrations and impact load are some of the environmental effects. The optical systems operating conditions are similar to the production conditions. These are kept constant via different arrangements like climate control and vibration damping. Under these conditions cardinal the radiation and heating by radiation can stimulate relative motions. These motion need to meet the given requirements. Contrary to the controlled operating conditions there are during the product lifetime different terms with a heavy change of environmental effects, for example transportation and handling proceedings. Relative movements caused by this proceedings need to be reversible within the give requirements.

Up to date, there are no proven measurement methods available to verify these demands. Today's measurement methods are indirect. They use the measurement of optical aberrations of optical doublets or whole systems. From these aberrations, for instance coma, it is possible to calculate the position of an optical element with respect to others. With this proceeding it is not possible to characterize a single mounting interface; the method captures always effects from several interfaces. His resolution depends on the concrete optical system and is not sufficient for given requirements. For conductive characterization of future lens mounting interfaces novel measurement solutions are necessary. A promising opportunity provides the nanopositioning and nanomeasuring machine (NPMM) [4].

Next steps

The given requirements may not be confidently achieved by today's lens mounting technology. The next step is the critical analysis of the state of the art in references to the given demands. On the basis of the results, novel approaches need to be generated. To verify the position stable mounting interface qualified measurement methods need to be developed and provided for the practical application.

For the mounting technologies subtasks system mounting and system adjustment (see fig. 1) future demands need to be generate and propagate.

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