Carl ZEISS AG

General presentation and Metrologies at ZEISS

Dr. Richard Quintanilha
Corporate **R**esearch and **T**echnology

21-22 September 2023

IMEKO TC10 Conference

FACTS

ZEISS Worldwide

Employees (rounded)

38,700

Locations worldwide (rounded)

100

Countries (rounded)

50

Revenue in € billion

8.8

Headquarters:
Oberkochen, Germany

Employees incl. Corporate functions and SSCs
Status: September 30, 2022

Investments in Research & Development

Innovations shape the future: Research and development teams at ZEISS are working hard to constantly expand our role as technology leader and market shaper. ZEISS has been making sustainable investments in R&D in order to achieve this goal.

New patent applications

638

R&D investments in € million

1,151

Investment by % of revenue

13%

FACTS

ZEISS Segments - Shaping the Future

Consumer Markets

Vision Care

Consumer Products

1.569 € billion in revenue

13,008 employees

Medical Technology

Microsurgery

Ophthalmic Devices

2.251 € billion in revenue

6,829 employees

Industrial Quality & Research

Industrial Quality Solutions

Research Microscopy Solutions

2.066 € billion in revenue

7,534 employees

Semiconductor Manufacturing Technology

Strategic Business Units

Semiconductor Manufacturing Optics

Semiconductor Mask Solutions

Process Control Solutions

2.757 € billion in revenue

6,215 employees

Status: September 30, 2022

Manufacturing trends determine the trends of manufacturing metrology

Trends of Manufacturing

High performance parts	Faster production	More complex parts	New Materials

Challenges and Trends in Manufacturing Metrology

increasing integration / reducing measuring time / automatic data processing	**Fast**
reducing measuring errors / uncertainty	**Accurate**
verification of measuring uncertainty	**Reliable**
measuring inaccessible parts / increasing information density	**Flexible**
increasing variety of measuring techniques	**Holistic**

Enabling New Vision

Consumer Markets

Vision Care

- Eyeglass lenses & accessories
- Devices for vision tests & eye measurements
- Platforms and applications for opticians and consumers

Consumer Products

- Binoculars & spotting scopes for nature observation
- Hunting optics
- Mobile photography
- Lenses for Photography & Cinematography
- Industrial lenses

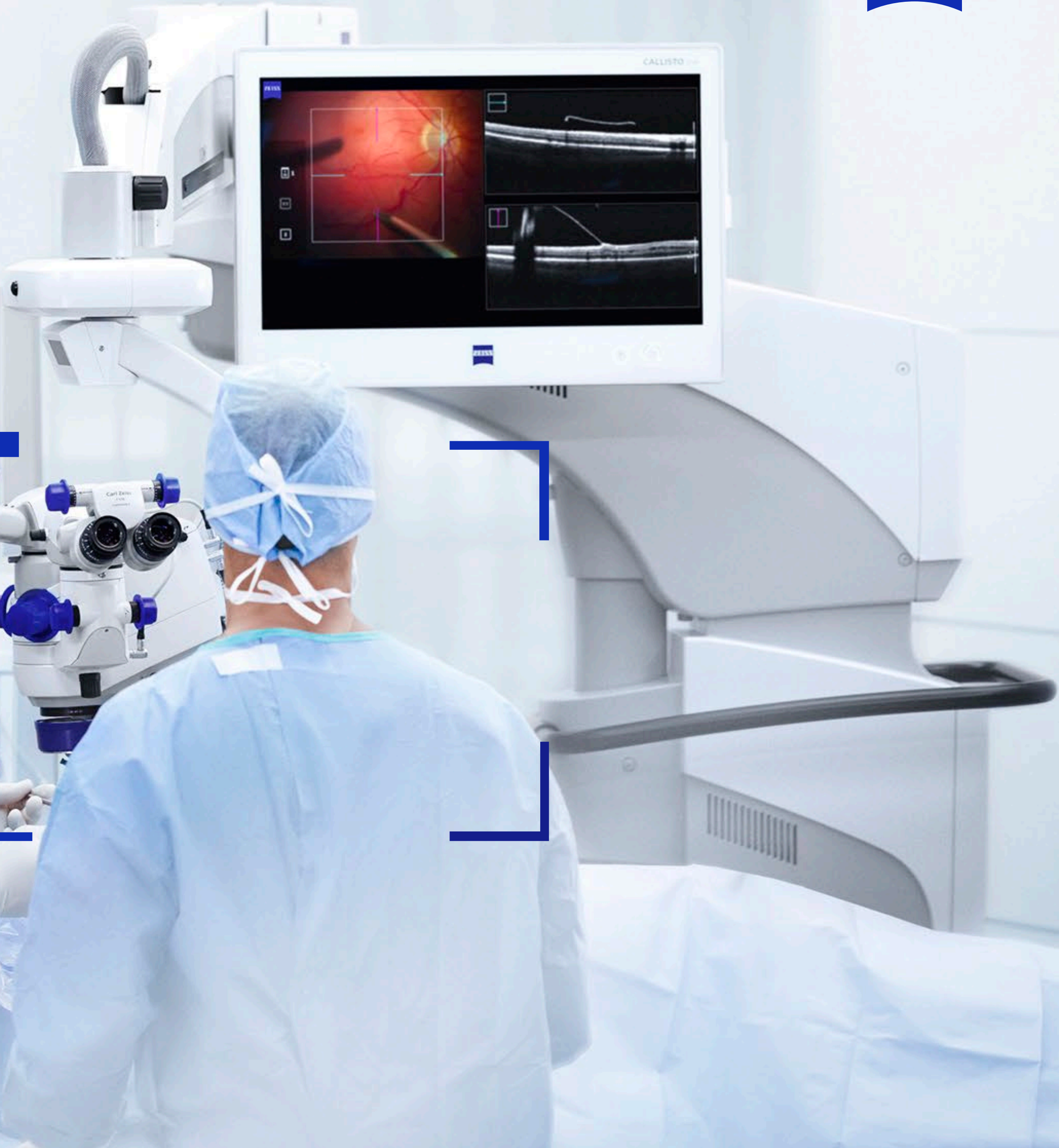
MediTec

Ophthalmology (OPT)

- Comprehensive solutions to diagnose and treat eye diseases
- Systems and consumables for Cataract, Corneal Refractive, Glaucoma and Retinal applications
- Focus on networking of systems and the integrated management of data, to make workflows in hospitals and medical offices efficient

Microsurgery (MCS)

- Complete product range of visualization solutions for minimally invasive surgical treatments (e.g. Neuro, ENT, Dentistry)
- Intraoperative diagnostics that improve surgical procedures by providing information beyond what is visible to the human eye (fluorescence, confocal, AI image processing)
- Intraoperative workflows that support surgical treatments beyond visualization



ZEISS Medical Technology

Enabling Ophthalmologists

Even the simplest medical treatments and routine surgeries are a real challenge in the Brazilian rainforest. Dr. Jacob Cohen founded the “Project Amazonas” aid program. Twice a year a group of surgeons and a team of medical personnel visit the interior of the Brazilian Amazonas region with medical technology from ZEISS for ophthalmic examinations and operations.

ZEISS IOLMaster 700

Assuring Quality and Precision – Seeing even the finest Details

Industrial Quality & Research

Industrial Quality Solutions

- Contact and optical measuring systems
- Computed tomography
- Measuring, analysis & management software

Research Microscopy Solutions

- Light microscopy
- Laser scanning microscopy
- Electron microscopy
- X-ray microscopy

Making Living Cells Visible

The first prototype of a phase-contrast microscope built by ZEISS in Jena (1936) based on Zernike's design:

Frits Zernike (Nobel Laureate, 1953)

First phase contrast microscope

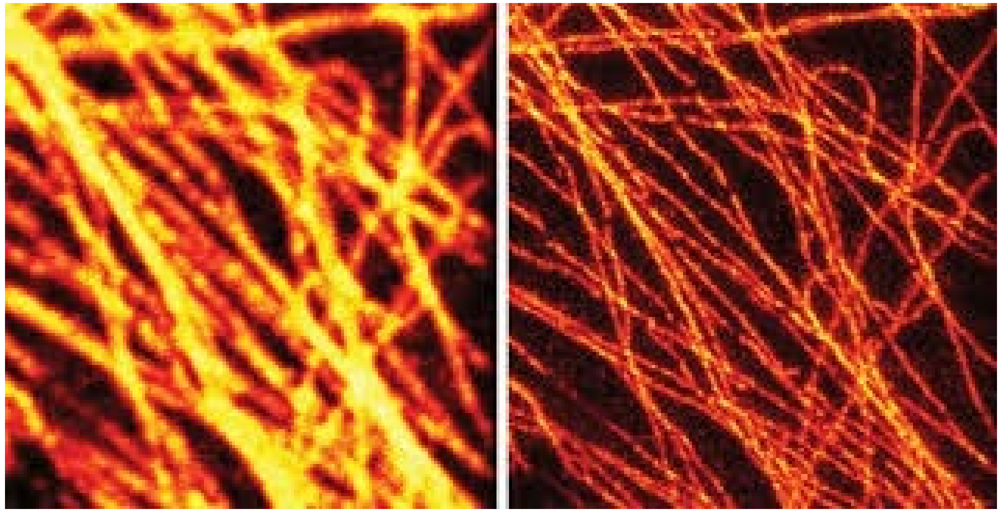
First film on cell division by Kurt Michel with the aid of the newly-invented phase contrast microscope (1943):

Meiosis in the spermatogenesis of the grasshopper

Resolution Beyond the Diffraction Limit
PhotoActive Localization Microscopy Principle

The ZEISS Elyra system is based on the PALM Principle, developed by Eric Betzig and Harald Hess.

Eric Betzig
(Nobel Laureate, 2014)

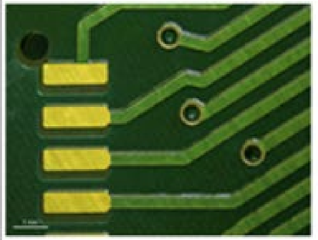


Comparison of confocal and PALM images

- Sequential imaging of blinking fluorescence proteins
- Combined with localization of the center of each signal
- Enables better separation of structures
- Maximum resolution: approx. 10 nm

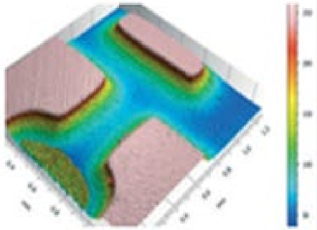
6 keys applications segments of Industrial Microscopy

Visual Inspection

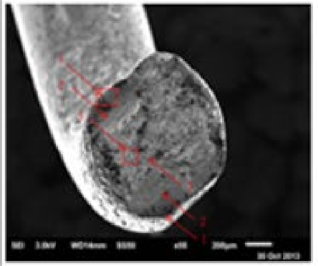


Metallography

Surface Characterization

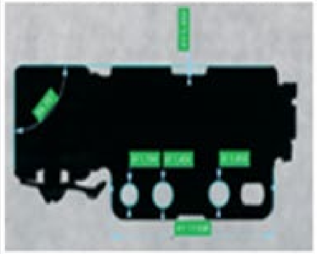


Failure Analysis



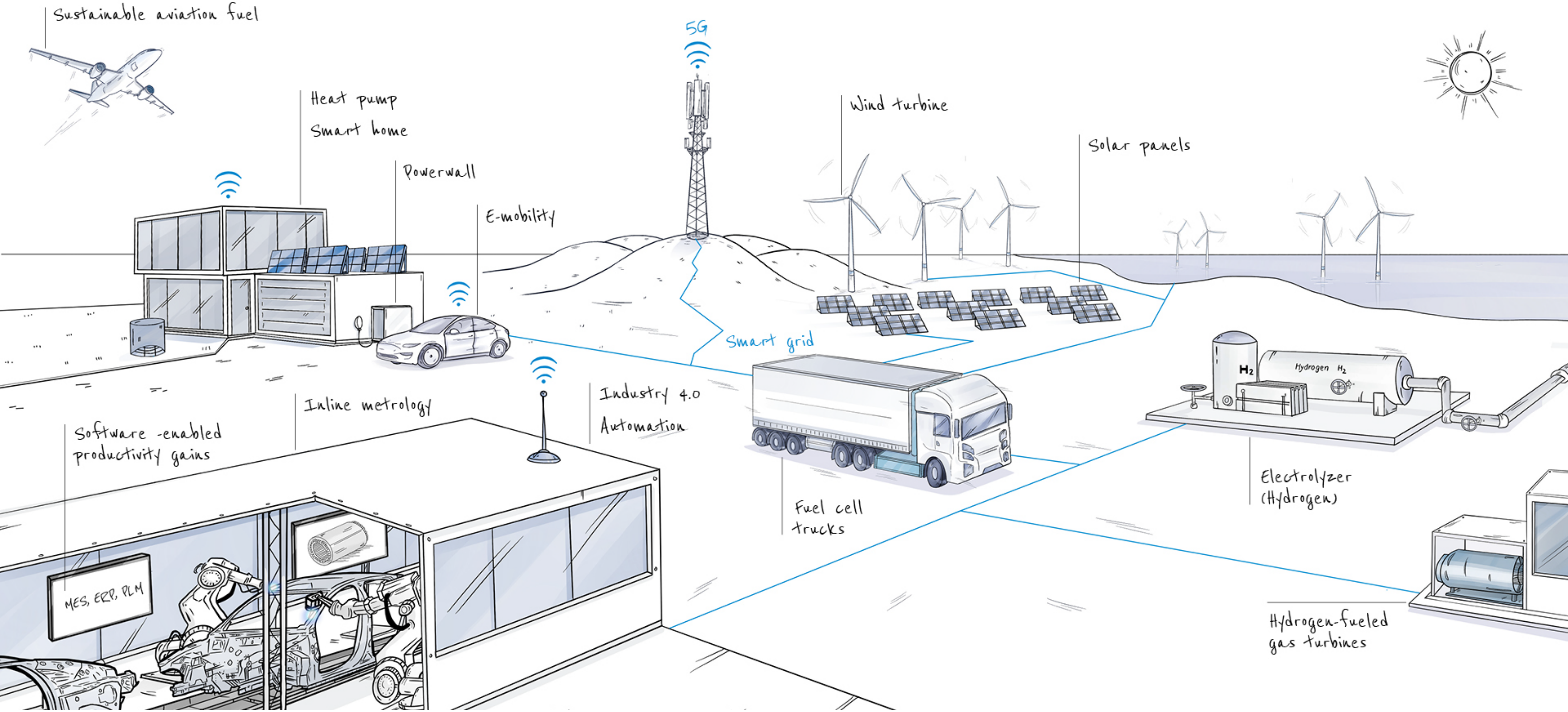
Particle Analysis

Optical Measurement

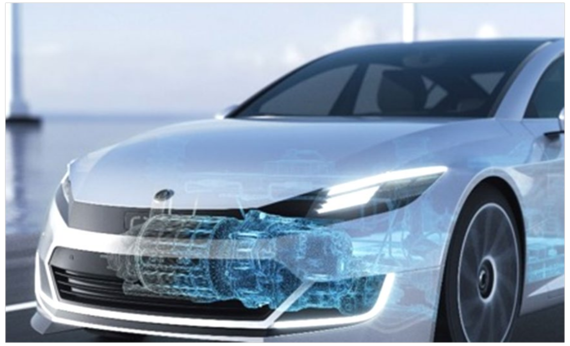


Decarbonization is one key driver for market transformation

New metrology applications arise, while others disappear



ZEISS Industrial Quality Solutions
Customer segments

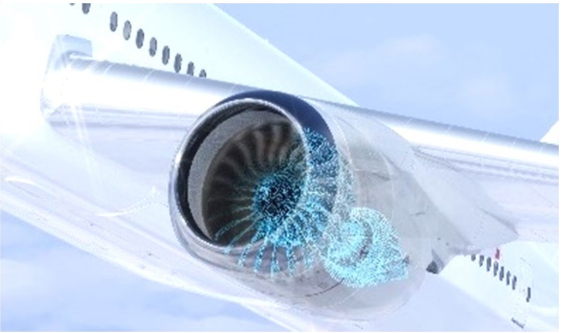


Automotive, NEV, ICE, Car-Body

Machine Tools & Engineering & Heavy Machinery

Power & Energy

Medical



Aerospace & Defence

Electronics

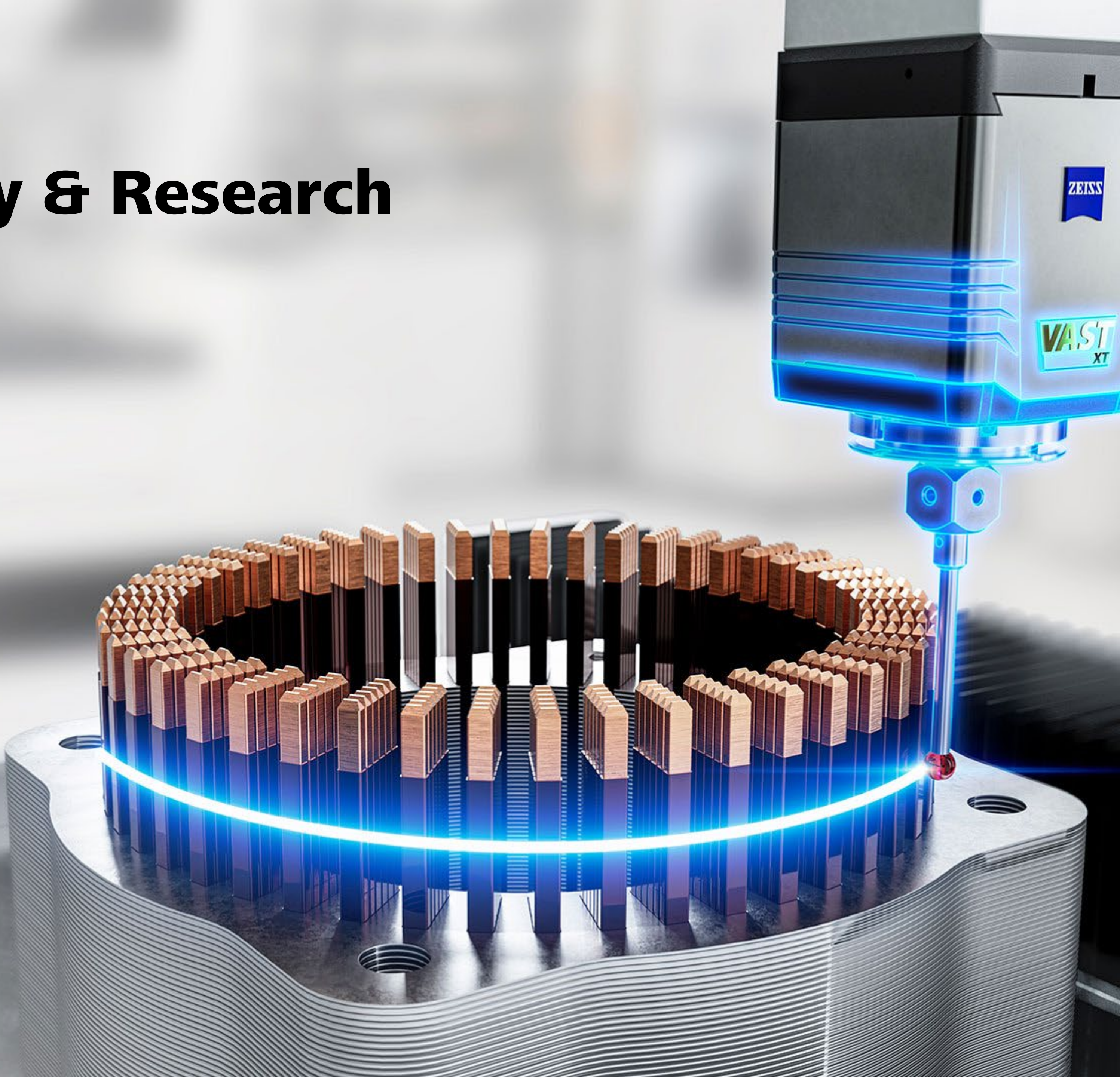
Metrology
Key to series production

Hardly any other vehicle manufacturer is focusing as consistently on the electrification of its portfolio as the Volkswagen Group. The first vehicle designed purely as an electric car is the VW ID.3. The main components of the electric motor are produced at the Volkswagen Group Components plant in Salzgitter.

A prerequisite for this is a measurement solution that enables large-scale production.

ZEISS Industrial Quality & Research
Enabling eMobility

Together with Volkswagen, ZEISS developed a convincing measurement solution for quality assurance of the sophisticated engine concept. One challenge here was the nature of the hairpins, which pushed measurement methods from traditional engine construction to their limits. ZEISS therefore developed a measurement solution with VW enabling the car manufacturer to go into large-scale production with electric mobility.




ZEISS Industrial Quality Solutions
Aerospace

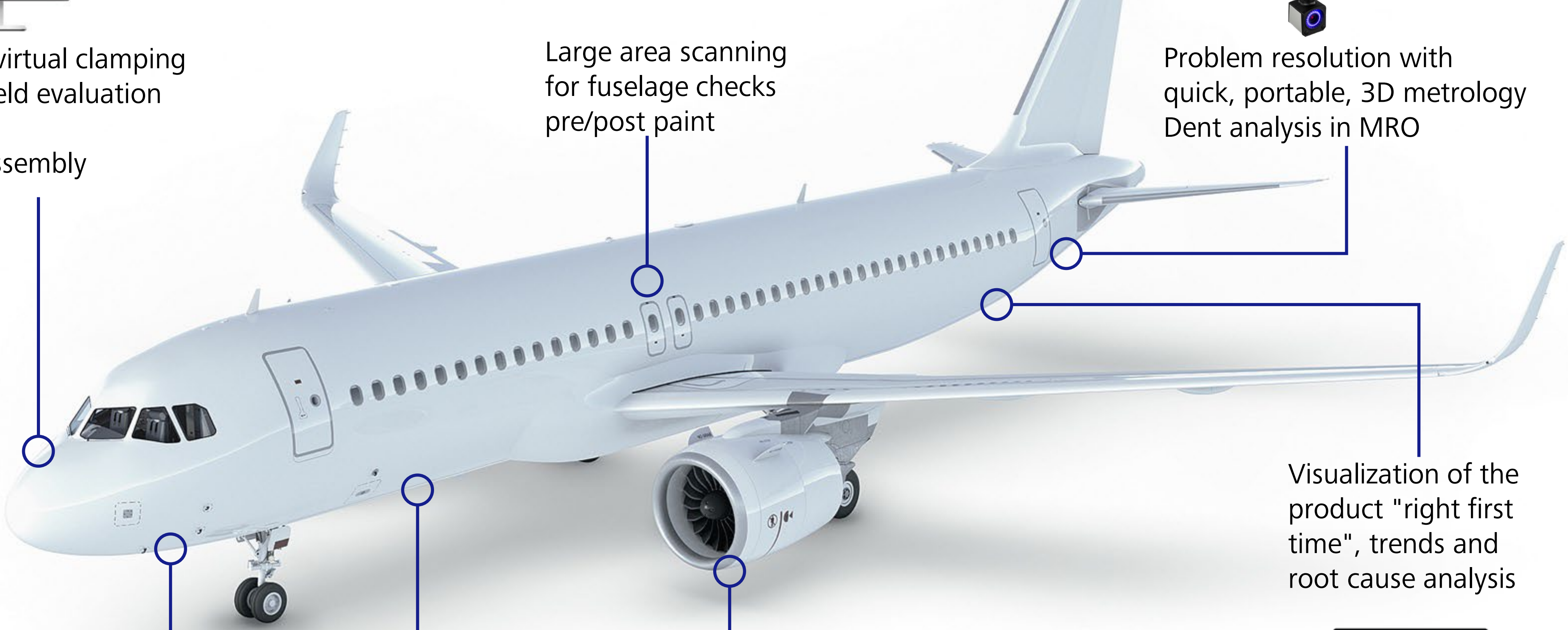
Aerostructure

Quality assurance, maintenance & repair of all aircraft structure components

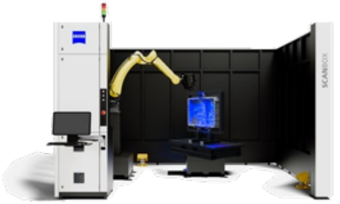
Dewarp/virtual clamping
3D full field evaluation
GD&T
Virtual assembly

Large area scanning
for fuselage checks
pre/post paint

Problem resolution with
quick, portable, 3D metrology
Dent analysis in MRO



Visualization of the
product "right first
time", trends and
root cause analysis



High throughput measurement
of diverse product ranges (ribs,
spars, fuselage sections)

Surface defect analysis

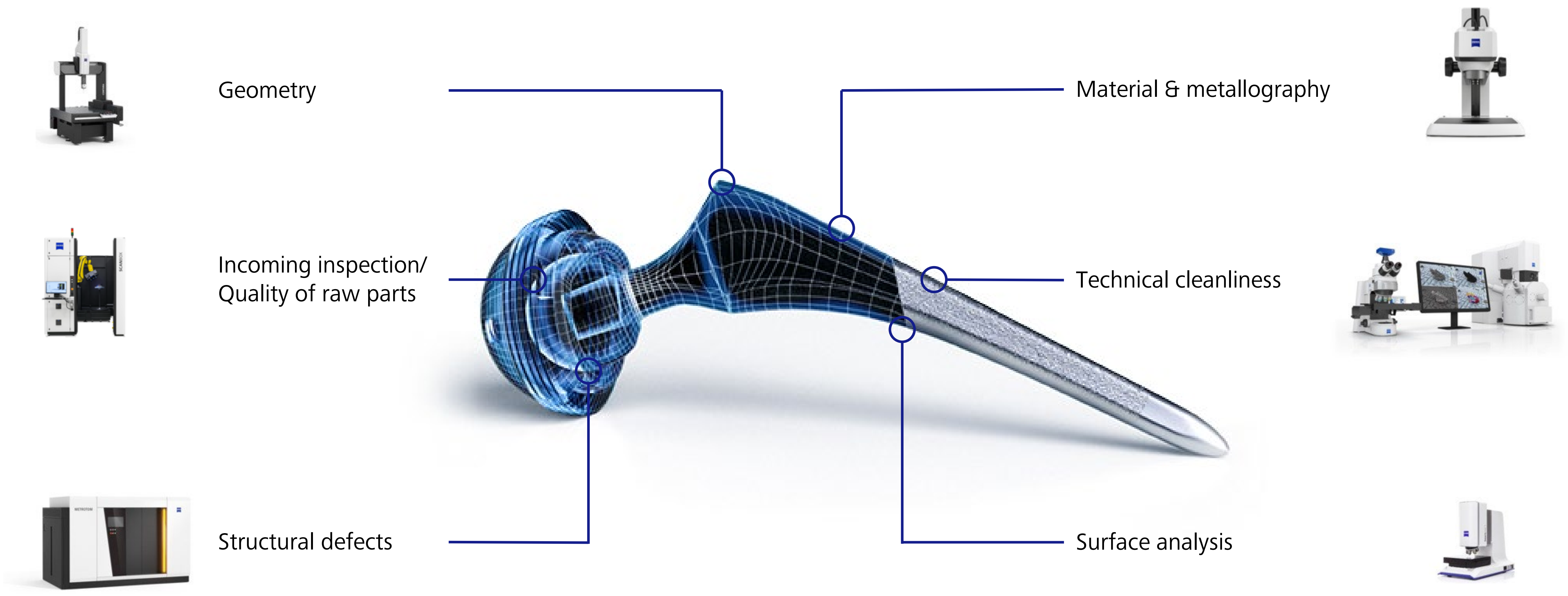
Precise multisensoric
CMMs from the small to
large safety critical parts

ZEISS Industrial Quality Solutions

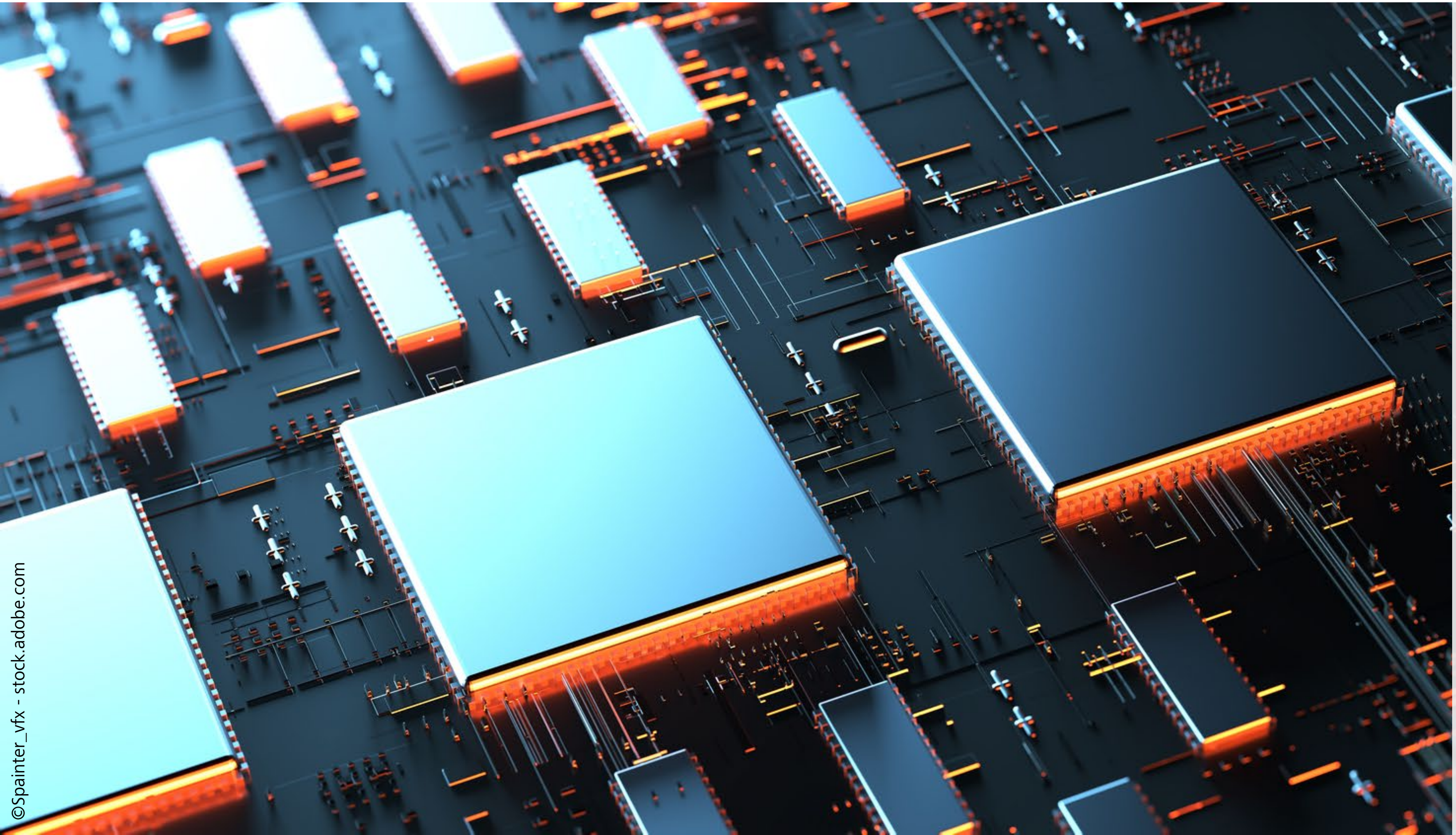
Medical

For all types of orthopedic and dental implants

Quality assurance for medical metal components (conventional and additive)



Dealing With Big Data



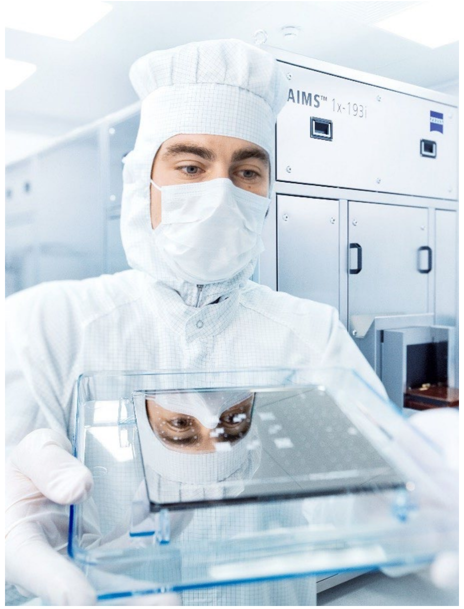
- Challenges in data storage, documentation and sharing arise in an ever-changing digital environment.
- New methods are needed to process huge and complex data.

SMT Business Units

Semiconductor Manufacturing Optics

- Lithography optics
- Mirror blocks and wafer chucks
- Optical systems, metrology devices and components for wafer inspection and lithography lasers
- Synchrotron optics
- Collectors

Photomask systems



- Mask metrology
- Mask tuning
- Mask repair
- Mask qualification
- Automation applications

Process Control Solutions

- Multibeam electron microscope (Multi SEM/eBeam)
- 3D Tomography

Semiconductor Manufacturing optics play a keyrole in structuring microchips

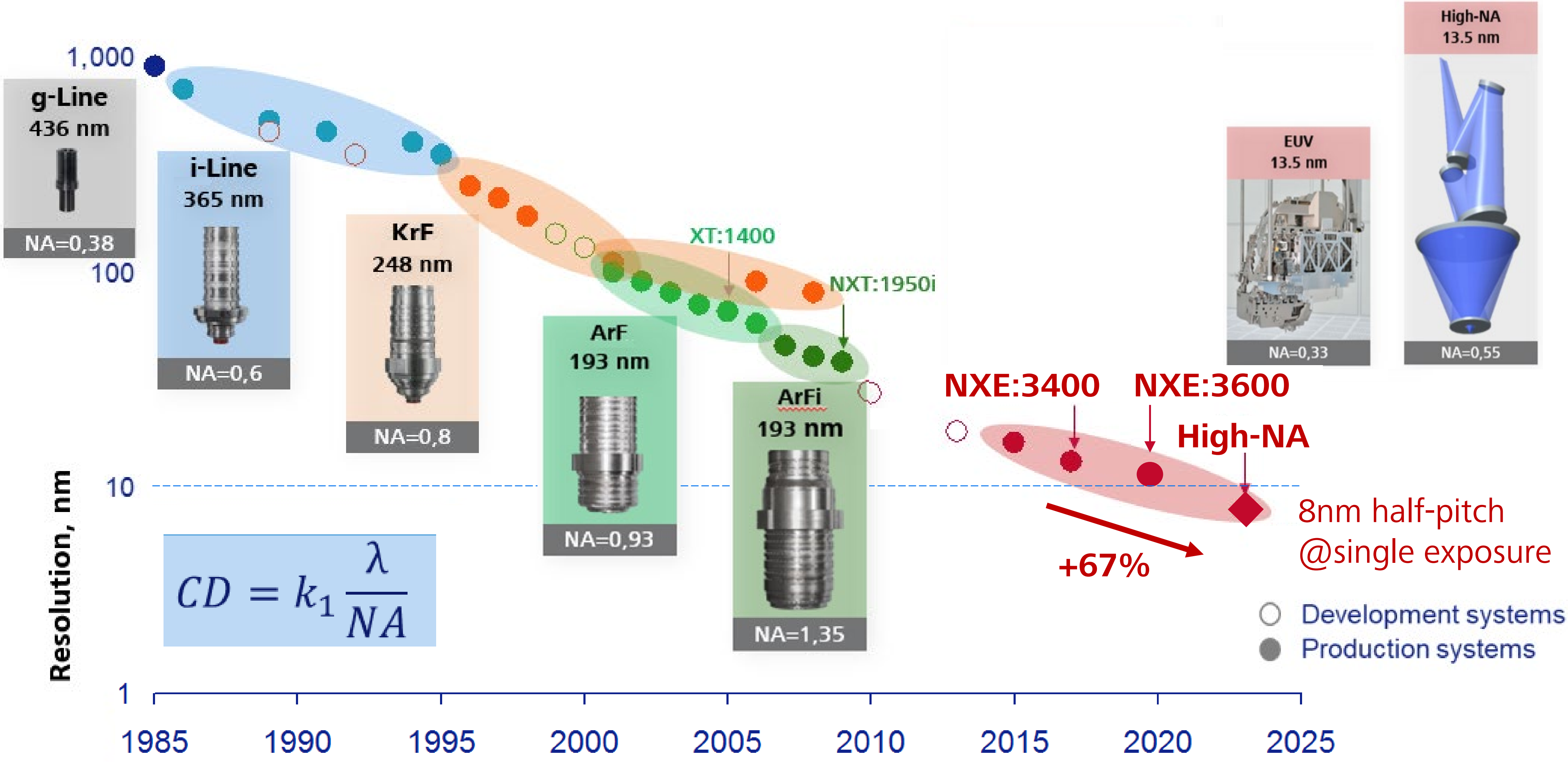
ZEISS

DUV-Waferscanner (Deep Ultraviolet) of our strategic SMT-partner ASML

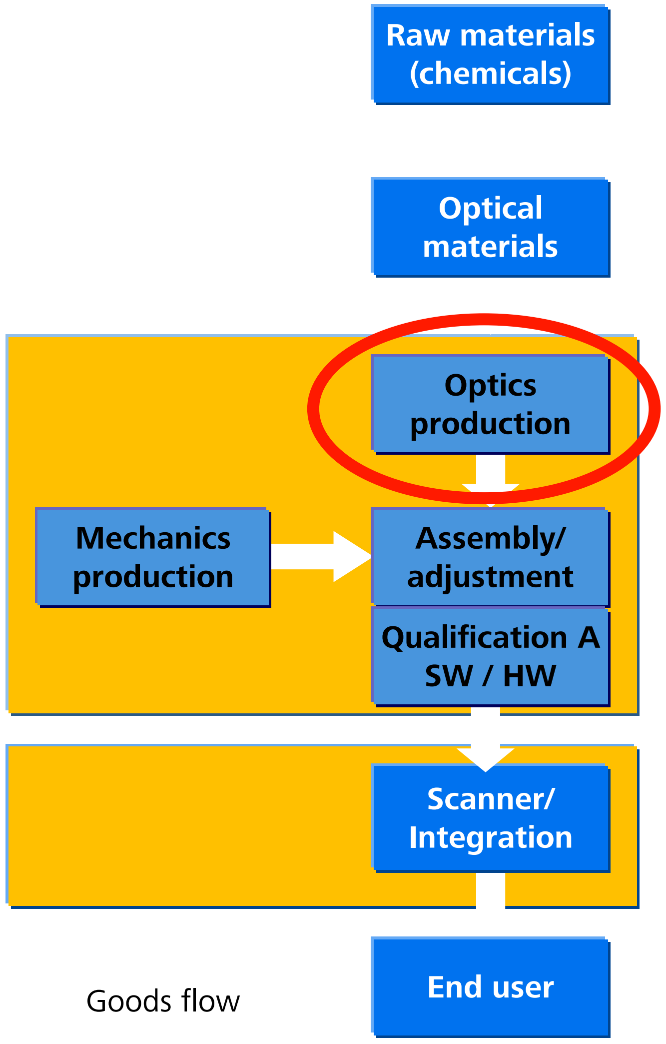
Source: ASML

Lithography roadmap

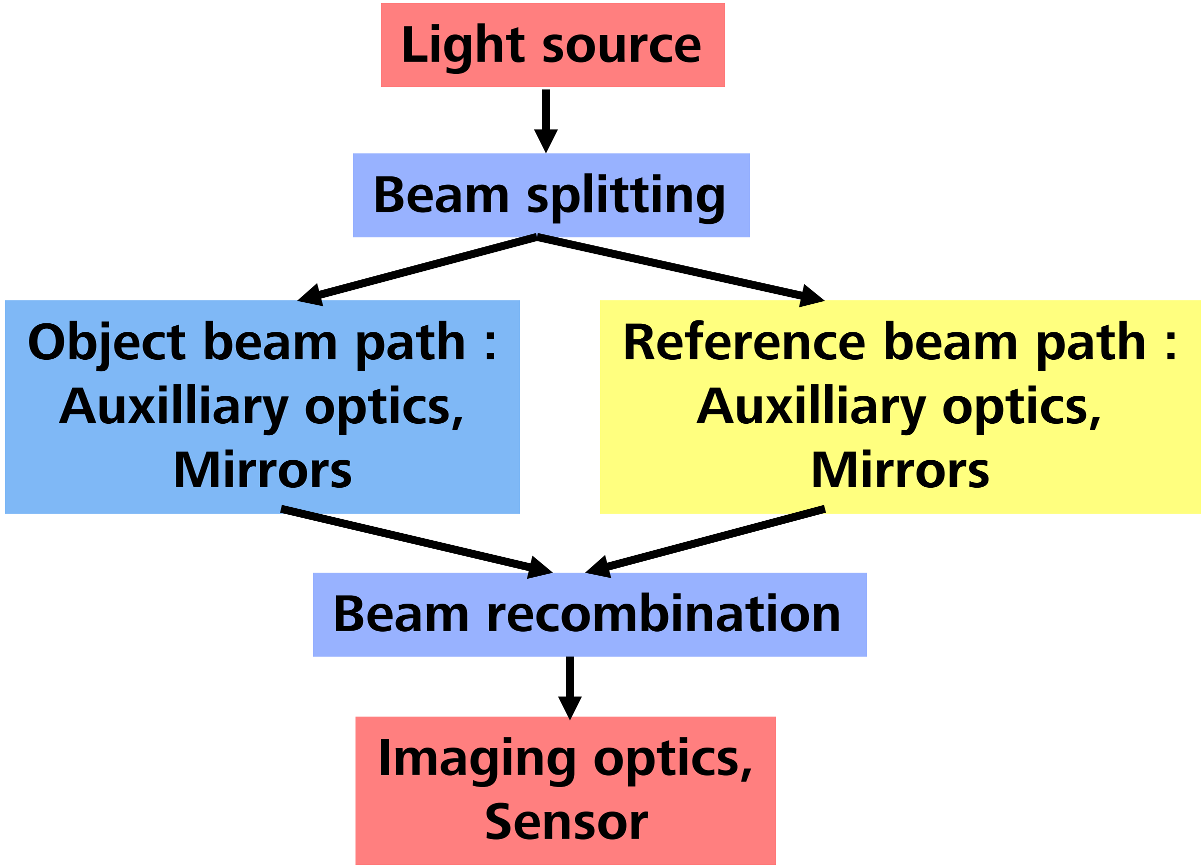
Enabled by wavelength reduction and increase of NA



Projection Optics
Leading edge technology and process control enable EUV optics.



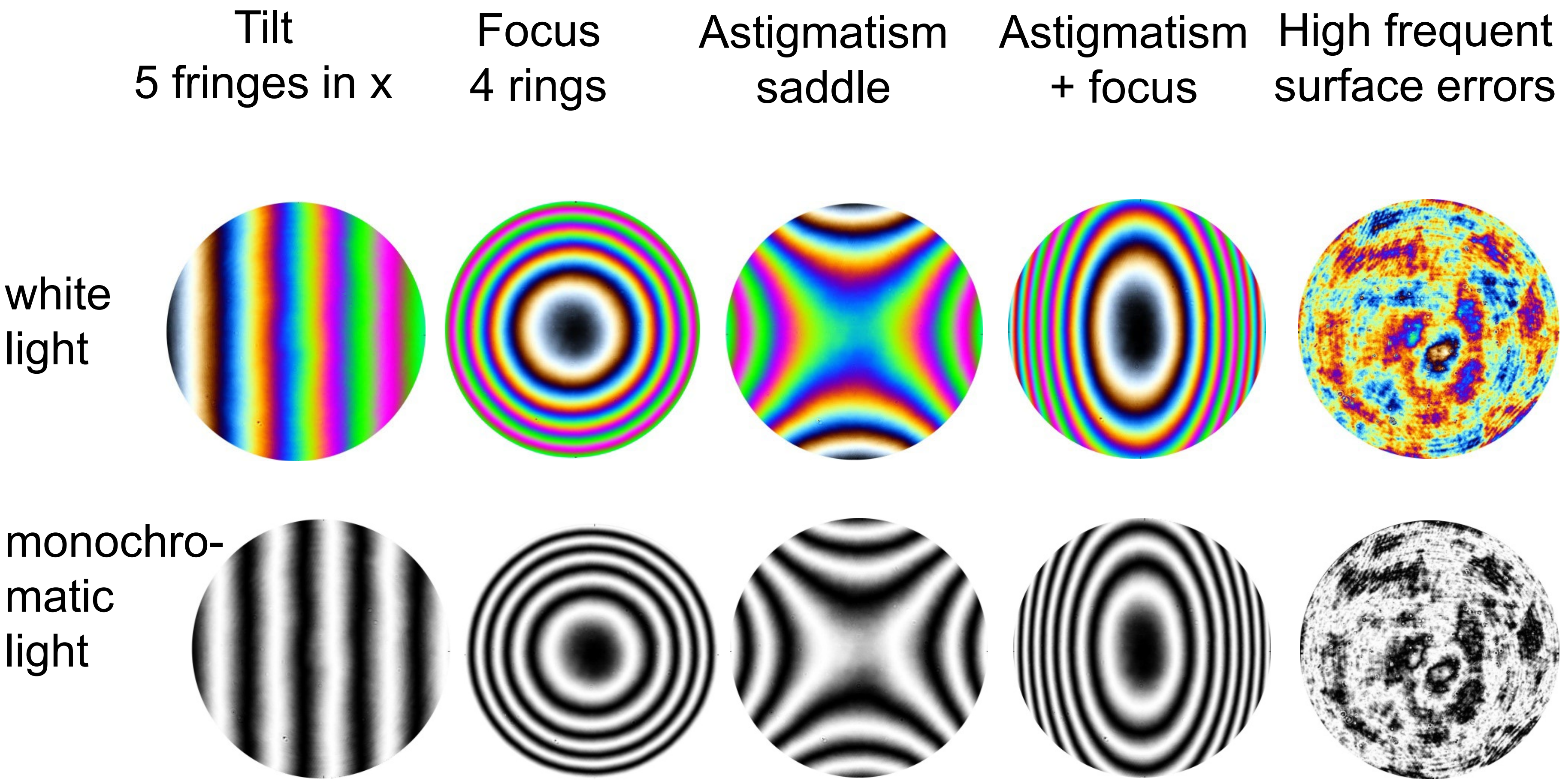
Principle of an interferometer



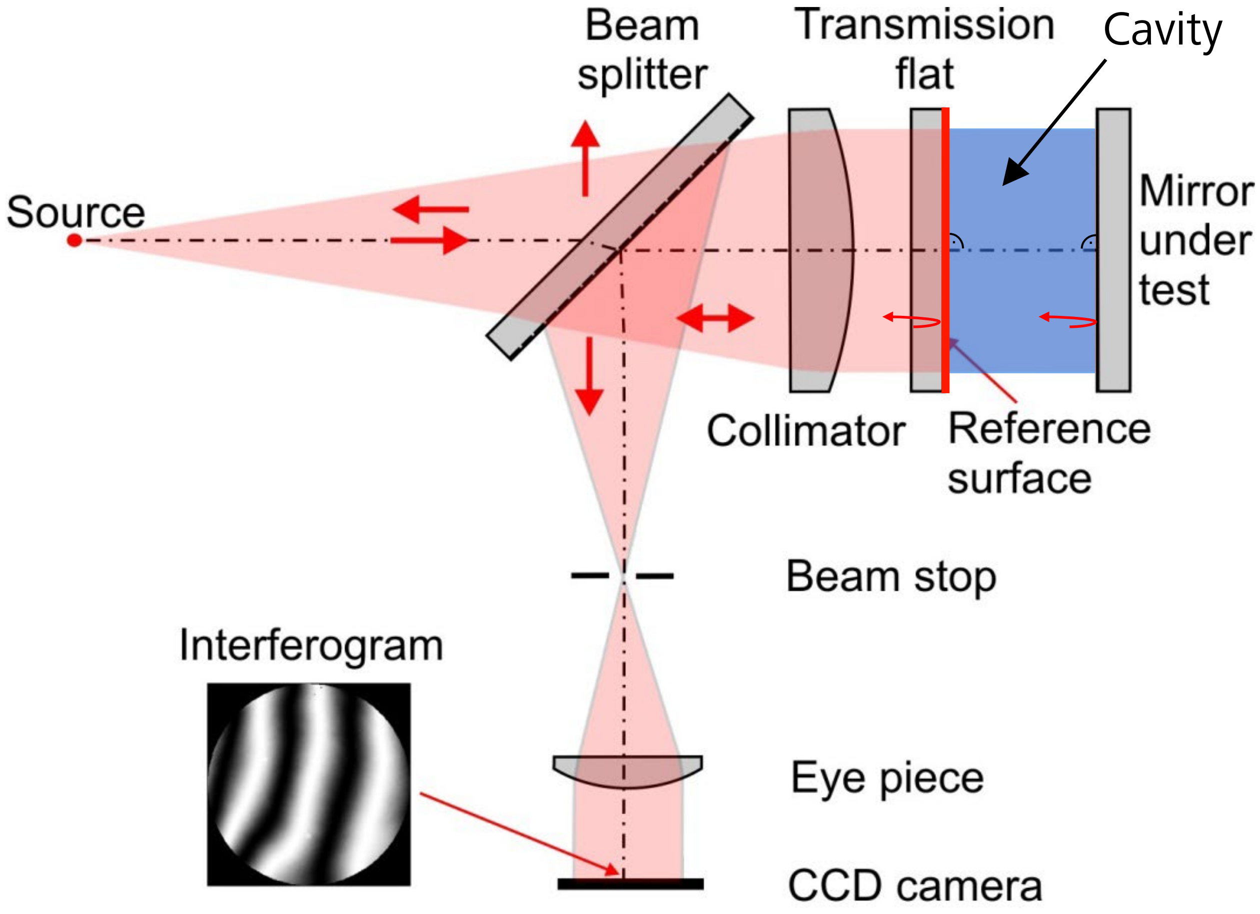
Many different design possible depending on application:

Accuracy vs Complexity vs Manufacturability etc…

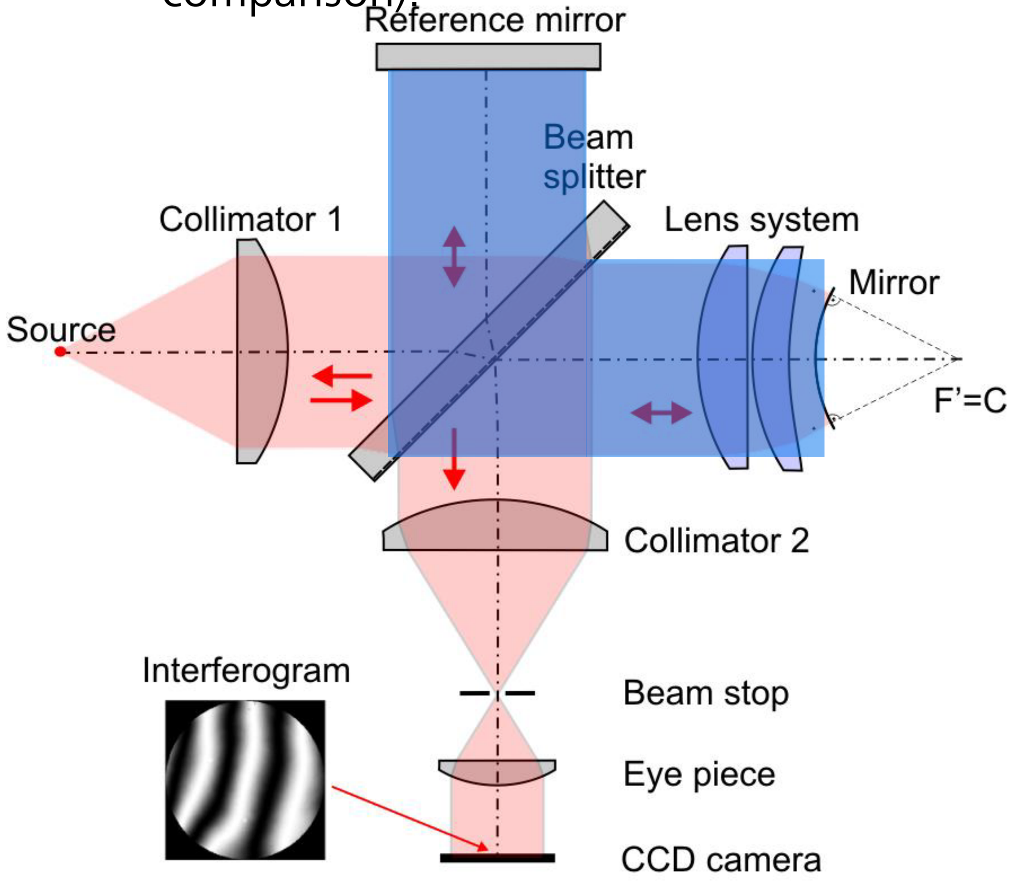
Examples for surface deviations



The Fizeau interferometer is a preferred instrument for optical surface metrology

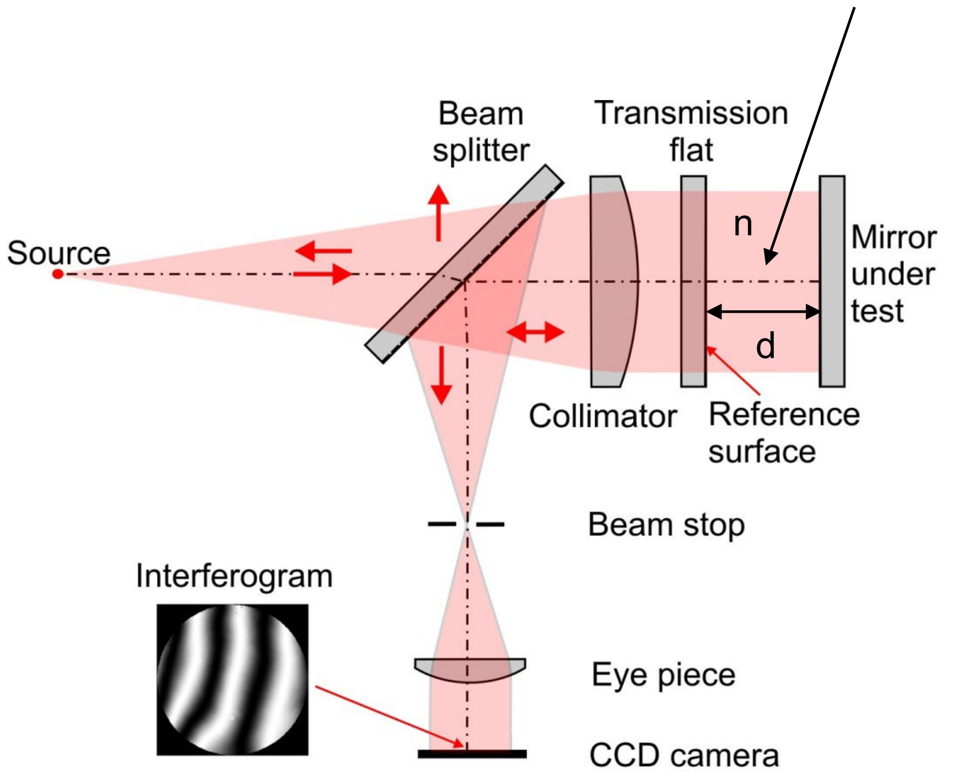


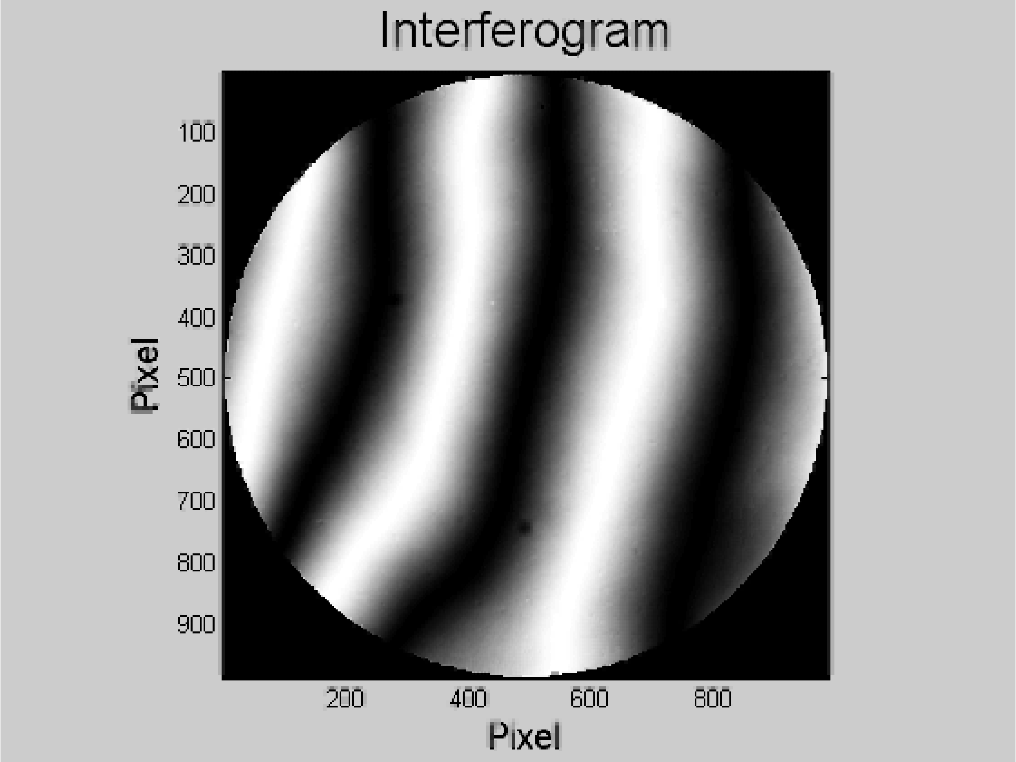
Twyman-Green-Interferometer (for comparison):



Phase shifting is achieved by altering the OPD between reference and test surface

$$OPD(x,y) = 2nd(x,y)$$



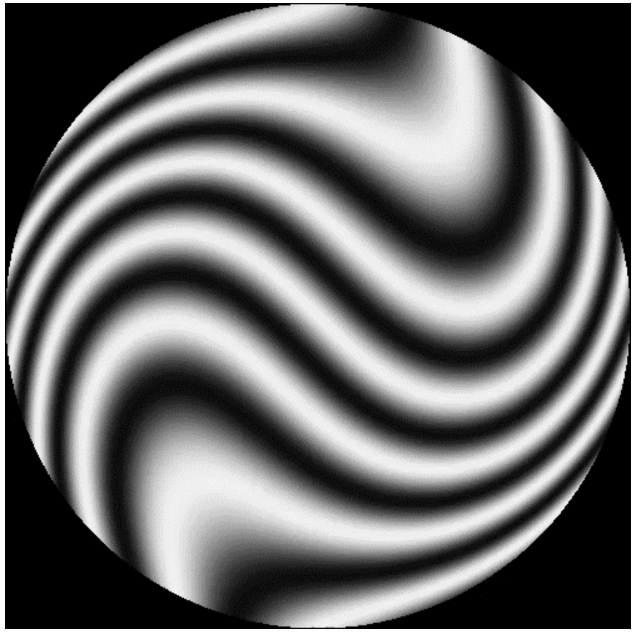


$$I(x,y) = a(x,y) + b(x,y) \cdot \cos \phi(x,y)$$

Phase of the interferogram: $\phi(x,y) = \frac{2\pi}{\lambda} \cdot OPD(x,y) = \frac{2\pi}{\lambda} \times 2n.\,d(x,y)$

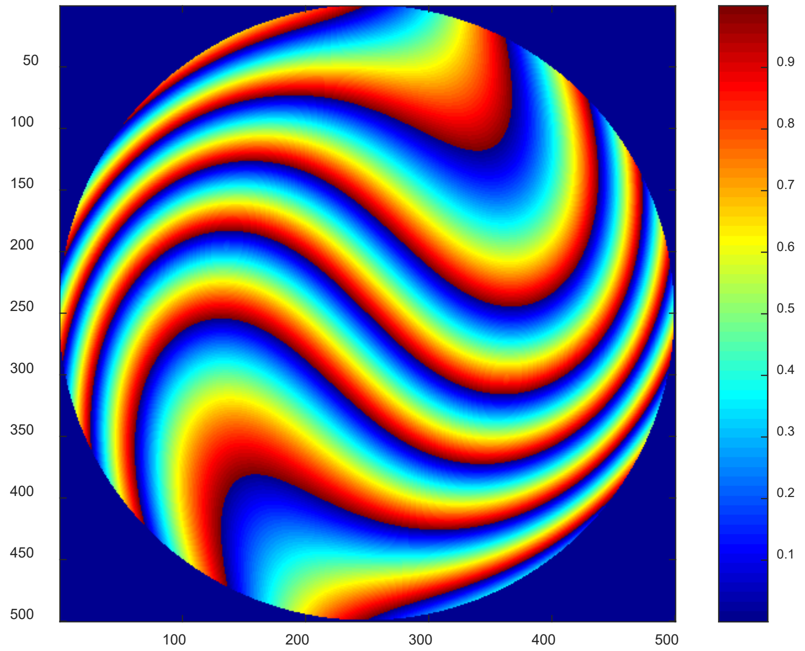
Image Acquisition and phase calculation
Phase Shifting method

Interferograms



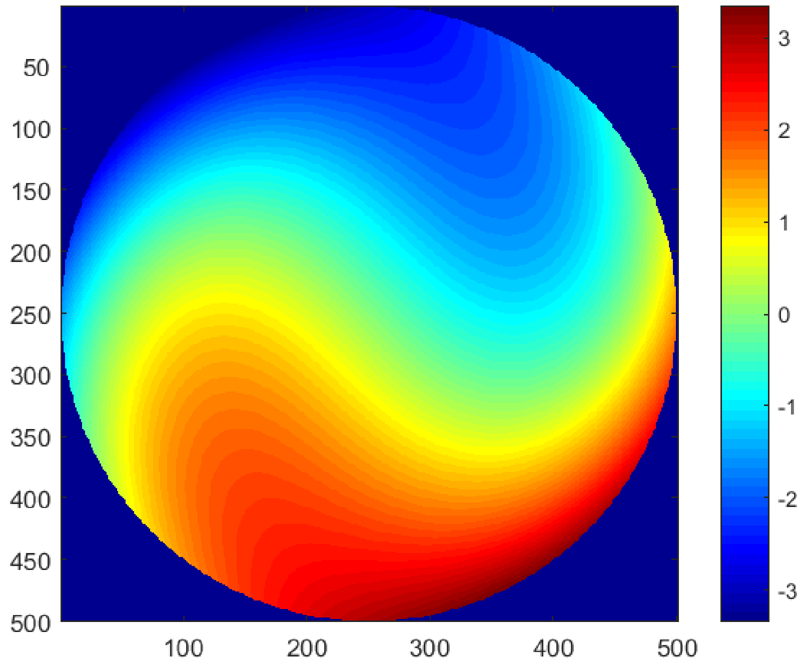
$I(x,y) = I_0 \cdot [1 + V \cdot \cos(\phi(x,y) + \delta\phi_i)]$

Wrapped wavefront



$\phi(x,y) \; mod \; 2\pi$

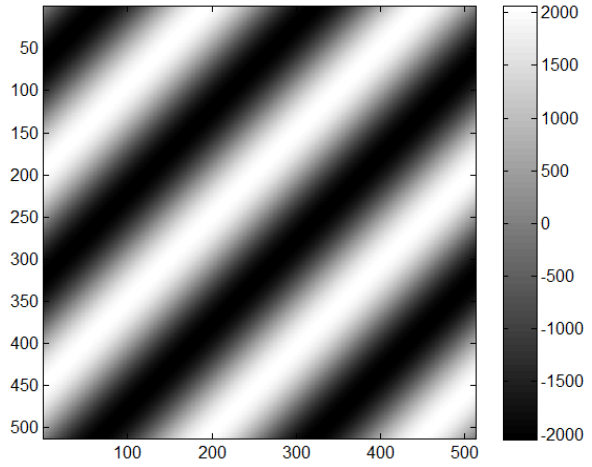
Unwrapped wavefront



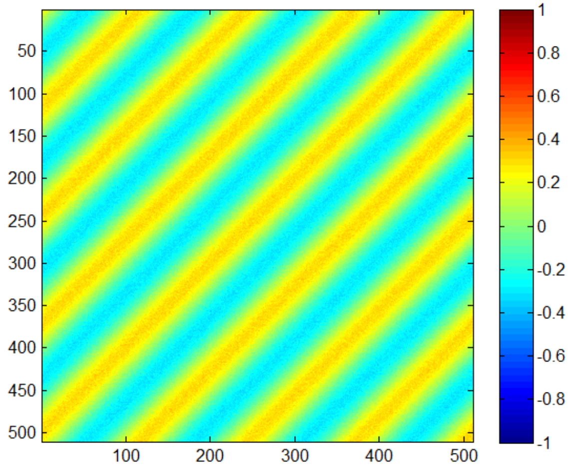
$h(x,y) = \frac{\lambda}{4\pi} \cdot \phi(x,y)$

Examples for Phase artifacts due to disturbances during the acquisition of the image sequence

Interferogram

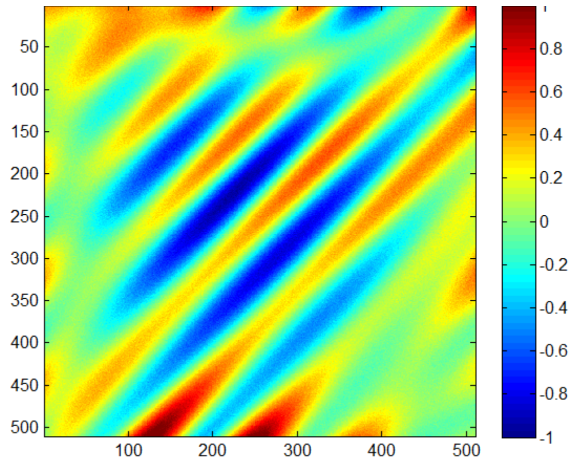


Wavefront error due to vibrations

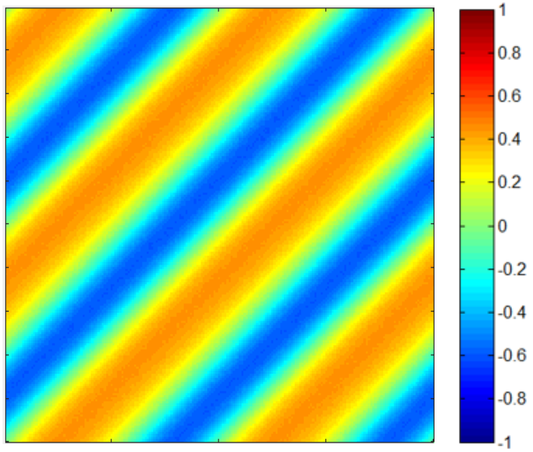


⇒ **Interferometer Calibration**

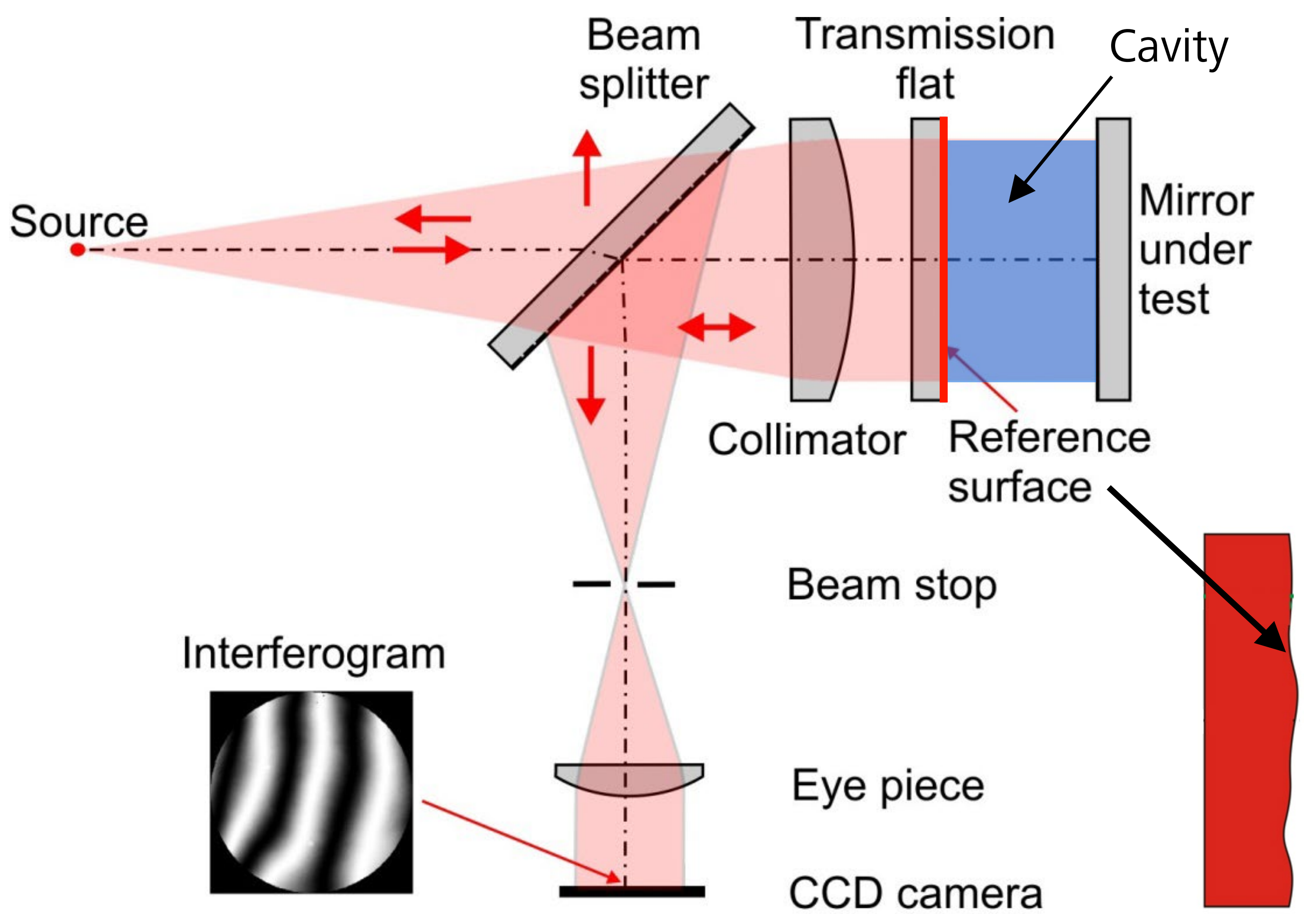
Wavefront error due to air turbulence



Wavefront error due intensity variations



Interferometer calibration



Optical path deviations in the cavity affect the measured wavefront most seriously.

Essentially, all other optical path deviations affect reference and sample wavefront in the same way ➔ ΔOPD ~ 0

The cavity must be calibrated

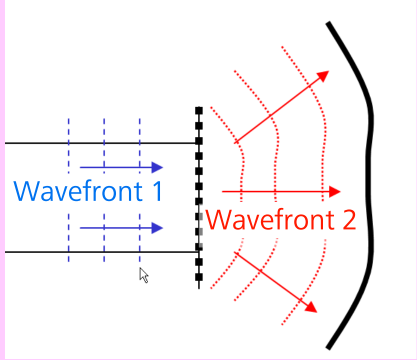
i.e.

- Rotation averaging to Separate non-rotationally symmetric deviations of sample and interferometer
- Absolute calibration of the glass (CGH)

What determines the measurement accuracy?

Ideal case :

Wavefront according to grating equation

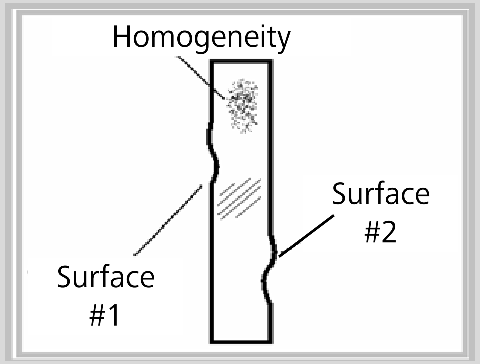


Ideal Material, grating profile, manufacturing, Structure position

Real case:

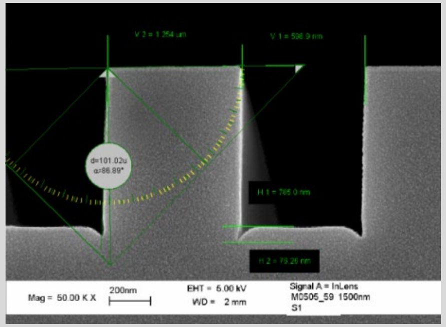
Phase errors caused by

→ Surface shape and homogeneity of the CGH-substrate

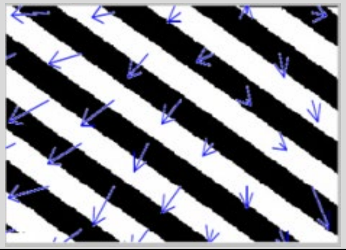


→ Rigorous errors of the grating (electromagnetic effects)

→ Rigorous errors due to deviations from the ideal profile form (Profile depth, aspect ratio, sidewall angle, Trenching…)



→ Position error of the lines = CGH-placement error



→ **Error contributions must be considered**

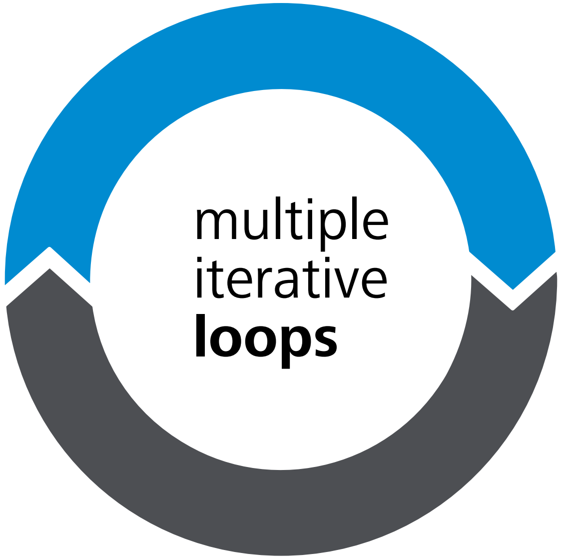
Challenges in EUV surface metrology

EUV Projection Optics
Figure control on atomic level

Computer Controlled Polishing

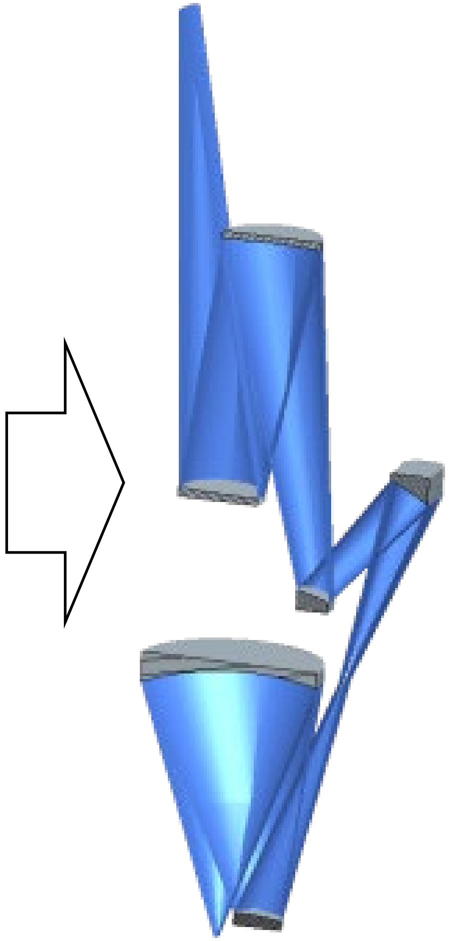
Ion Beam for figure controle at atomic scale

Figuring process



Highly accurate metrology

Interferometric Surface Metrology



Polishing technologies and metrology closing the loop

Projection Optics
Critical quality parameters for polishing of optical surfaces.

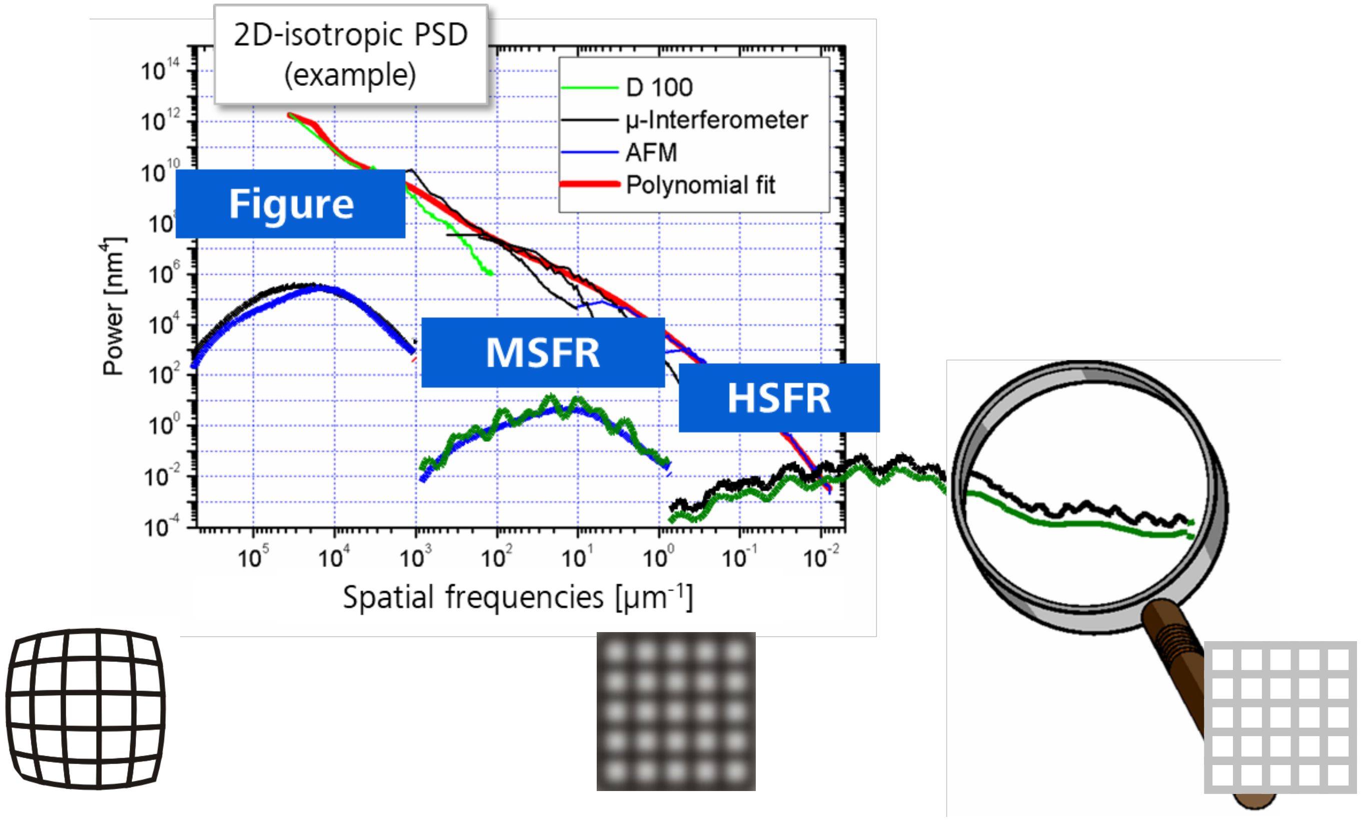
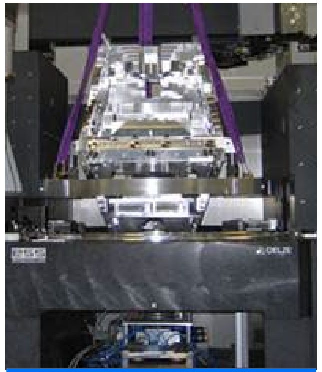


	Figure	MSFR	HSFR
	aberrations	Scattering light in the illuminated field	Reduced reflectivity
Substrate	**CD Uniformity, Overlay**	**Uniformity, Contrast**	**Transmission/Reflectivity**
Coatings	**Stress, layer thickness, gradient**	**replication**	**Roughnening, smoothing**

EUV project optics

Requirements on figure errors are ~20x tighter for EUV surfaces

Immersion-Objective
(193 nm)



EUV-Objective
(13.5 nm)

Maréchal-criterion: wavefront error < λ/14 RMS
(a wavefront can be regarded as diffraction-limited if its RMS phase error is 14 times less than its wavelength)

refractive index

topography errors

total wavefront errors

$$\Delta\phi_{total} = \sqrt{N}(n-1)\frac{\Delta h}{\lambda}$$

numbers of optical surfaces

For examples:

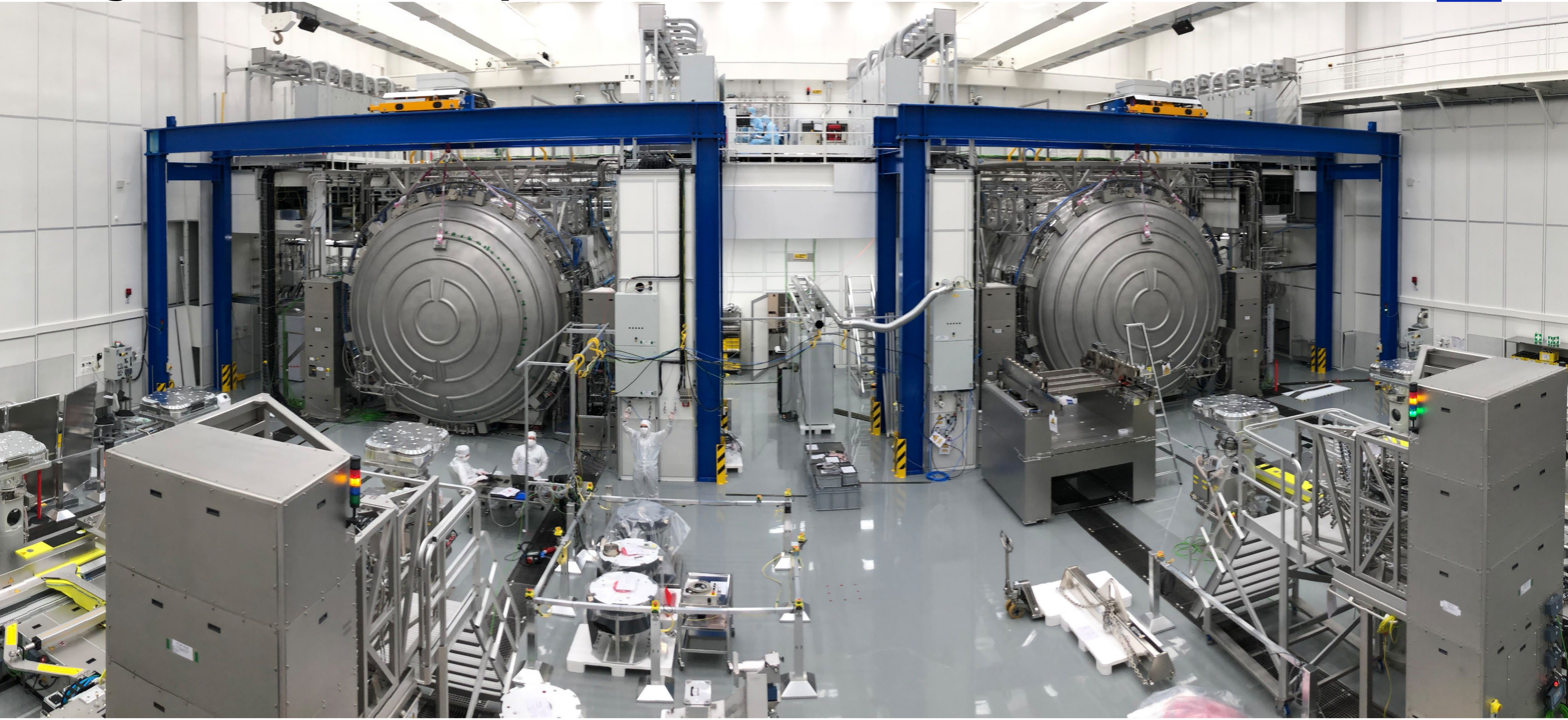
$$\frac{\Delta h(mirror\ surface\ @\lambda = 13.5\ nm)}{\Delta h(lens\ surface\ @\lambda = 193\ nm)} = \sqrt{\frac{60}{6}} \times \frac{1}{4} \times \frac{13.5}{193} \approx 0.05$$

reflective surface 4x more sensitivity to errors than transmissive surface

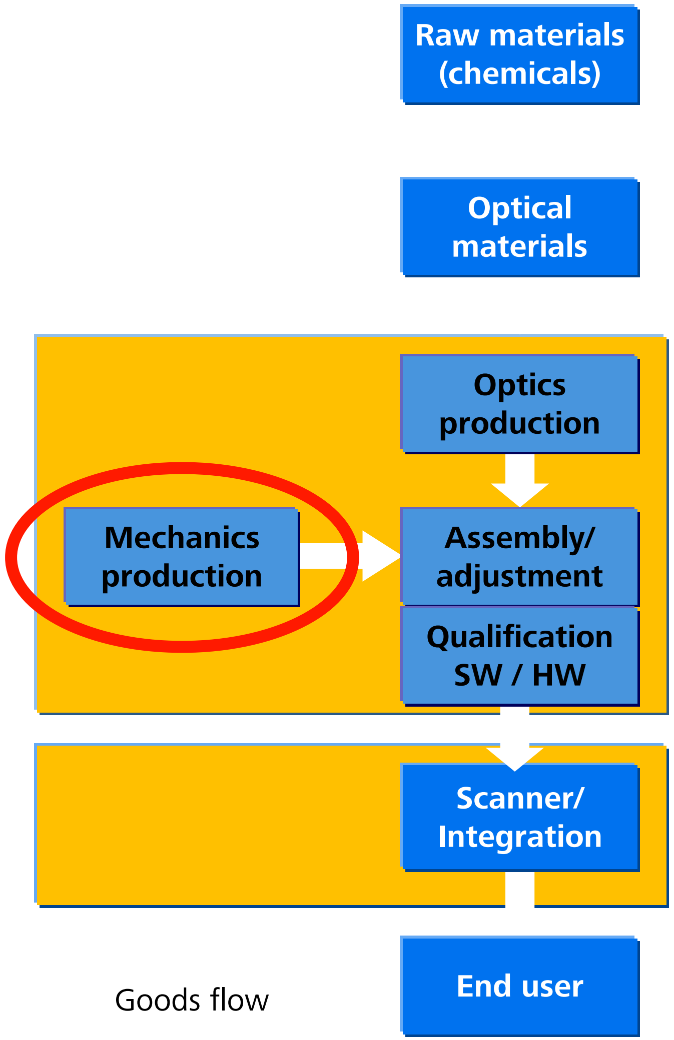
Typical requirements: Δh(@193nm) ~ 0.3 nm

⇒ Δh(@13.5nm) ~ 15 pm

High-NA EUV test setup

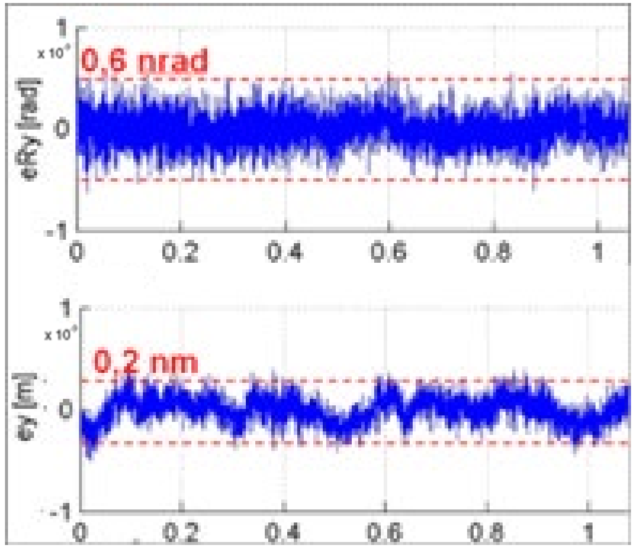


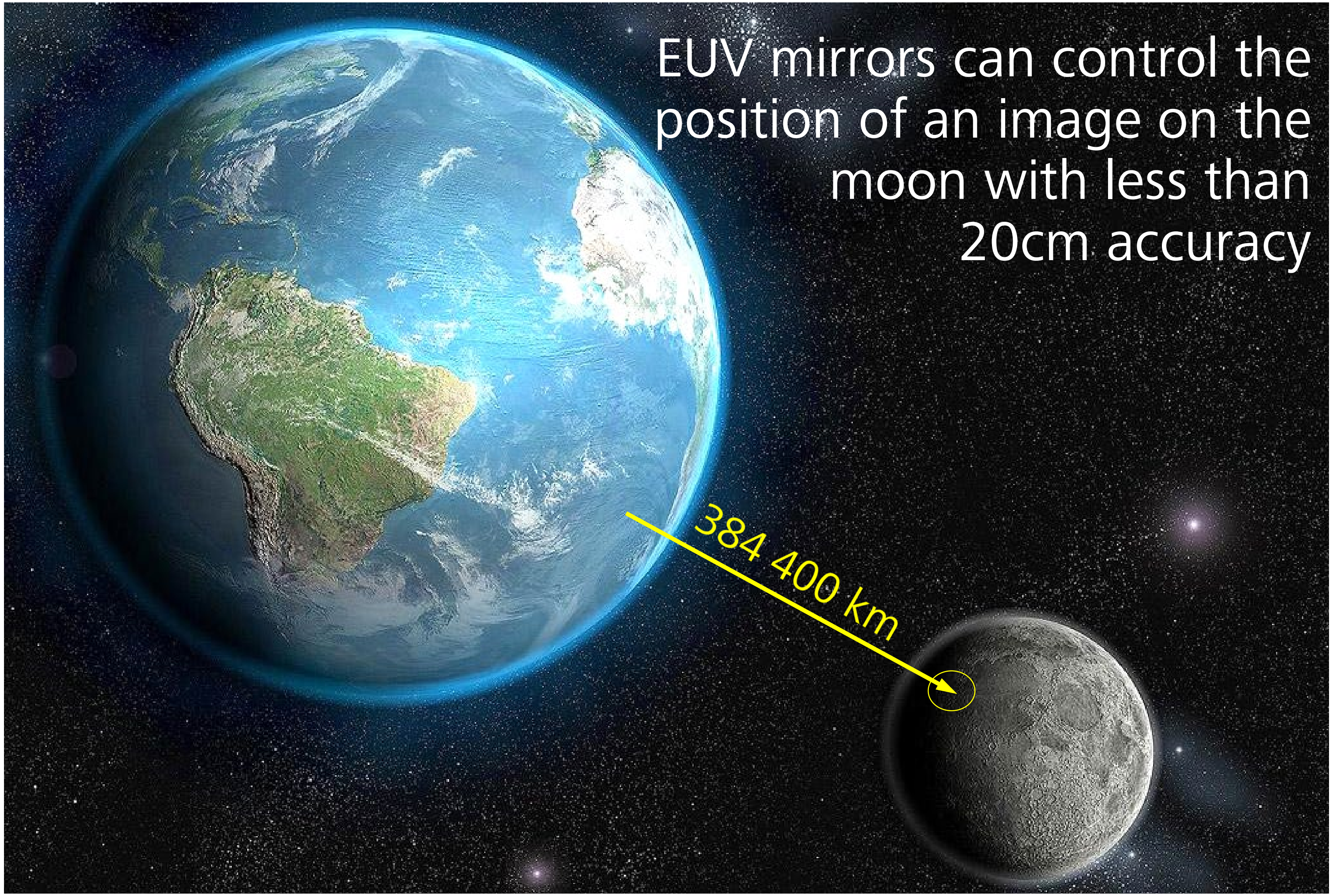
Projection Optics
Leading edge technology and process control enable EUV optics.



Starlith® 3400: Projection Optics
Mirror tilts controlled with sub nrad accuracy.

Test module for EUV mirror positioning





What limits the measurement accuracy?

Electrical drift effects
Position deviations
Camera noise
Coherent artifacts
Straylight
Optical design of the interferometer
Quality of the optical components
Retrace-effects
Polarisation effects
Mechanical Drift
Air turbulence
Temperatur effects
acoustic influences
Radiation
Vibrations
Handling effects
Insufficient calibration
Varying environment conditions
Sample handling
Shot-Noise
Heat of electric components
Electrical drift effects
Position deviations
Camera noise
Coherent artifacts

ZEISS

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JENOPTIK

MORE LIGHT

KYOCERA

TNO

ims chips

ZEISS

Successful Cooperation with Partners from Research and Industry – Funded by the European Union and the Federal Republic of Germany

ECSEL JU

KDT JU
KEY DIGITAL TECHNOLOGIES JOINT UNDERTAKING

Bundesministerium für Bildung und Forschung

Bundesministerium für Wirtschaft und Energie

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Thank you for your attention!

Special thanks to

All my colleagues that provide me with a lot of Material for this presentation and the whole metrology team for the support during the preparation.

Seeing beyond