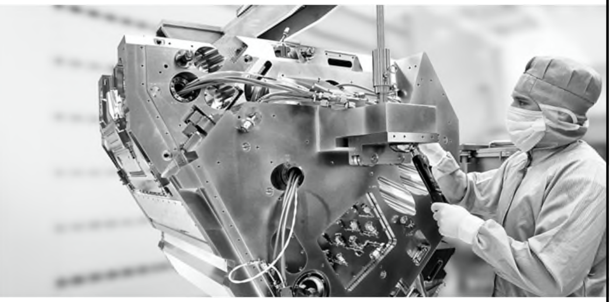
Thermal Fluid-Structure Analysis



Timo Laufer
System Engineering
March, 19th, 2014

Content

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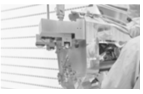
The ZEISS Group around the world
Fiscal Year 2012/13


Semiconductor Manufacturing Technology
€934 million in revenue 2,898 employees


Industrial Metrology
€528 million in revenue 2,239 employees


Microscopy
€629 million in revenue 2,801 employees


Medical Technology
€1,032 million in revenue 3,450 employees


Vision Care
€841 million in revenue 9,586 employees

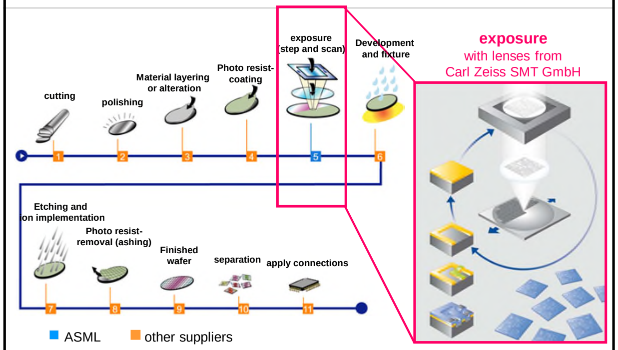

Camera Lenses, Sports Optics, Planetariums
€195 million in revenue 767 employees

re than 50

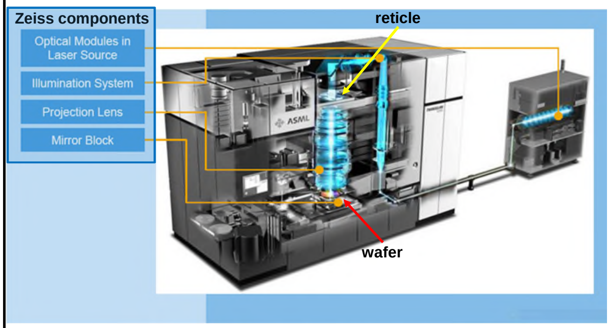
approx. 24,000 employees

Sites & employees
Carl Zeiss SMT GmbH

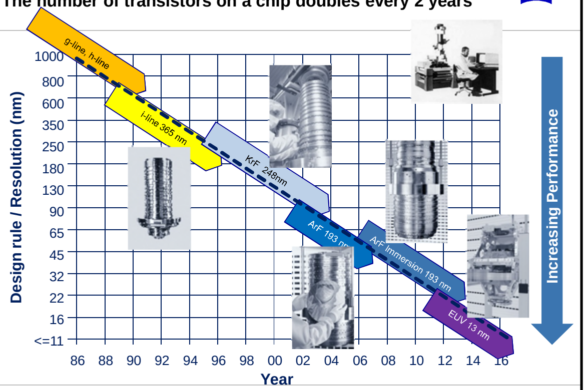
Sequence of Producing Micro Chips



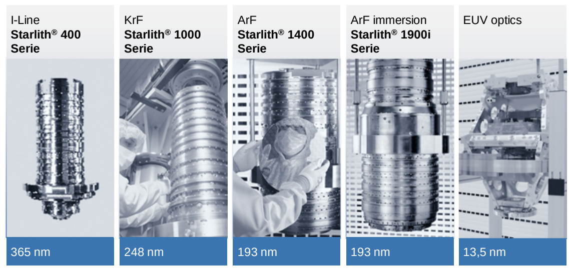
Exposure Machine
ASML TWINSCAN XT:1950i



Moore's Law
The number of transistors on a chip doubles every 2 years



Projection Lenses of Carl Zeiss SMT GmbH



Projection Lens *Starlith® 1900i*

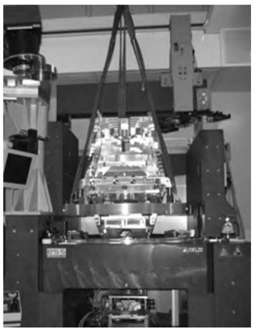
Technical Key Data

- Wavelength 193 nm
- NA 1.35
- **RMS optical performance < 0.9 nm**
- Height 1290 mm
- Weight 1080 kg

Content

1. Carl Zeiss SMT GmbH and Products
2. **Basic Principles of EUVL (<u>E</u>xtreme <u>U</u>ltra <u>V</u>iolet <u>L</u>ithography)**
3. Essential System-Components, thermal Boundary Conditions
4. Heat Transport Mechanisms in rarefied Gases
5. FEM-Model and Results of the Simulations
6. Summary and Benefits

Projection Optics *EUV – Alpha Demo Tool*



Key Technical Data

• Wavelength	13.5 nm
• Height	1500 mm
• Weight	790 kg
• Resolution	**50 nm (early PO)** **40 nm (AD1, AD2)**
• Aberrations	**< 3 nm (early PO)** **1.4 nm (AD1, AD2)**

EUV Mirror Specs: Compared to Real World

1000 km

2962 m

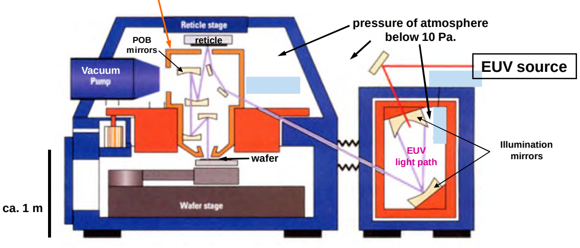
MET primary

100 mm

surface roughness corresponds **of ~ 0.2 nm to**

peaks of 2 mm in area of Germany

Alpha-Tool schematic Representation



This schematic shows the alpha exposure tool for the MEDEA+ EUV program.

Content

1. Carl Zeiss SMT GmbH and Products
2. Basic Principles of EUVL (Extreme Ultra Violet Lithography)
3. **Essential System-Components, thermal Boundary Conditions**
4. Heat Transport Mechanisms in rarefied Gases
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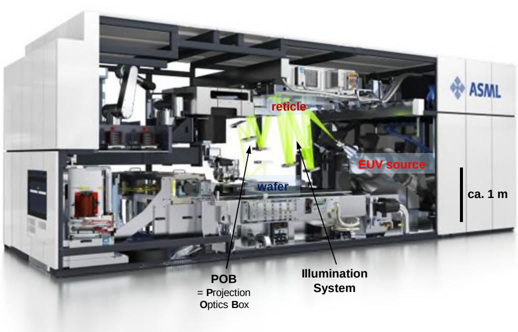
EUV-System



Thermal Boundary Conditions
Heat Loads and Heat Sinks

Heat Loads

- EUV source compartment, **total** **generated heat flux within the source >> 10 kW**
- EUV-light absorbed by the mirrors, **max. absorbed heat flux > 500 W**
- Actuators / motors, sensors, electrical components, …

Heat Sinks (Coolers)

- Water cooled heat sinks to dissipate the heat and
- heat shields at temperature sensitive components.

Thermal Boundary Conditions
Heat Transfer

Heat Transfer Mechanisms

- Heat conduction in solids
- Heat transfer solid / solid (contact resistance)
- Heat transfer in a rarefied gas (atmosphere in the EUV-system)
  → **p < 10 Pa** → **$0.001 < K_n < 0.1$** → **continuum with slip flow**
  - heat transfer in small gaps
  - fluid / solid interaction
- IR-radiation with consideration of
  - the view factors of **all** components
  - the emissivities of **all** components

Radiation is important specially for bigger distances between heat exchanging components and in case of high temperatures; the **hottest** components reach a temperature **>> 700 °C**.

Thermal Boundary Conditions
Output to be Evaluated

Output

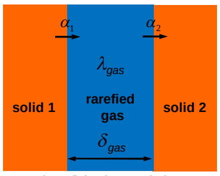
- **Transient** thermal analyses of the whole EUV system.
  → For the temperature sensitive components a **stability in the μK/min-range** must be reached.
- **Transient** thermoelastic analyses show the positioning drift of the optical elements over time.
  → The image position on wafer level **during wafer exposure** must be **smaller than some nanometers**.

Content

Heat Transfer in rarefied gases

$$htc = \frac{1}{R_{th} \cdot A}$$

$$R_{th} = \frac{1}{A_1 \cdot \alpha_1} + \frac{\delta_{gas}}{A_{gas} \cdot \lambda_{gas}} + \frac{1}{A_2 \cdot \alpha_2}$$



The rarefied gas is assumed to be a solid in all FEM-simulations.

R_{th}	:	Thermal resistance between heat exchanging solids 1 and 2
htc	:	Heat transfer coefficient between heat exchanging solids 1 and 2
$\alpha_{1,2}$	:	Heat transfer coefficient between solid and rarefied gas (atmosphere in the EUV-system)
λ_{gas}	:	Thermal conductivity of the rarefied gas (atmosphere in the EUV-system)
A_1	:	Convection area of fluid / solid boundary 1.
A_2	:	Convection area of fluid / solid boundary 2.
A_{gas}	:	Surface area of conduction in gas
δ_{gas}	:	Distance between heat exchanging solids 1 and 2

Sherman-Lees Equation

$$\frac{1}{htc_{gas}} = R_{th} \cdot A = \frac{\delta_{gas}}{\lambda_{gas}} + \boxed{\frac{\alpha_i + \alpha_j - \alpha_i \cdot \alpha_j}{\alpha_i \cdot \alpha_j}} \cdot \frac{\sqrt{\frac{\pi \cdot M_{gas} \cdot T}{2 \cdot R}}}{\left(1 + \frac{\zeta}{4}\right) \cdot p}$$

htc	:	Heat transfer coefficient between heat exchanging solids 1 and 2
R_{th}	:	Thermal resistance between heat exchanging solids 1 and 2
$\alpha_{i,j}$	:	**Accommodation factor between fluid and solids 1 and 2**
λ_{gas}	:	Thermal conductivity of rarefied gas (atmosphere in the EUV-system)
M_{gas}	:	Molecular weight of gas
R	:	Universal gas constant
ζ	:	Number of internal energy modes
p	:	Gas pressure
T	:	Gas temperature
δ_{gas}	:	Distance between heat exchanging solids 1 and 2
A	:	Convection area of fluid / solid boundaries 1 and 2

Continuum with Slip Flow

$$K_n = \frac{l_{mean}}{\delta_{gas}}$$

K_n	:	Knudsen number
l_{mean}	:	Mean free path
δ_{gas}	:	Distance between heat exchanging solids

The Knudsen number K_n is between $0.001 < K_n < 0.1$

→ **regime**
continuum with slip flow

→ **velocity slip**
the gas velocity at the wall differs from the wall velocity

→ **temperature jump**
the gas temperature at the wall differs from the wall temperature

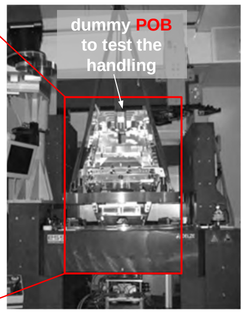
The accommodation factors $\alpha_{i,j}$ in rarefied gases were measured for different materials and different types of machining.

Content

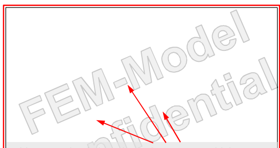
FEM Simulations
FEM-Model

Summary FEM Data:

Number of Nodes:	> 4 million
Number of Structure Properties:	> 50
Number of Fluids:	1 (atmosphere)
Number of Interfaces including thermal resistances:	> 300



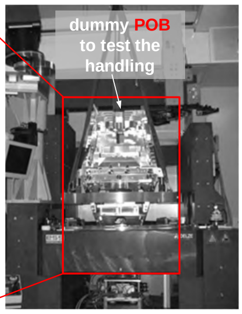
FEM Simulations
Results thermal Simulations



This FEM-simulation shows **hot spots**, which are short term effects in the beginning of the heating.

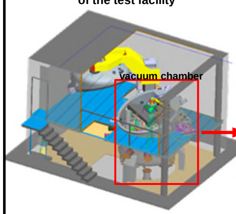
The EUV-system has different time constants:
- different thermal capacities and
- different thermal resistances from the heat sources to the heat sinks.

The heat loads of some heat generating components are transient, so that we have **transient heat loads as an input for a transient simulation**.



FEM Simulations
FE-Model POB Test Facility

schematic representation of the test facility



FE-model of the vacuum chamber

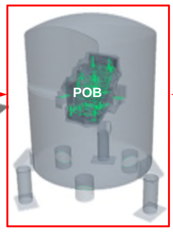
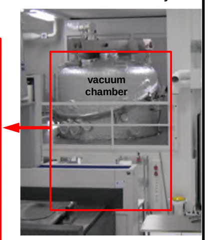


photo of the vacuum chamber within the test facility



Within the vacuum chamber different scenarios can be tested.

FEM Simulations
Results POB Test Facility (Vacuum Chamber)

Hot spots at the outside of the vacuum chamber can be seen according to the heat generating POB components.

The heat transfer mechanism from the heat generating POB components to the vacuum chamber is mainly radiation and conduction within solids.

FEM result of the vacuum chamber

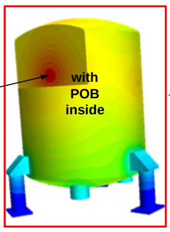
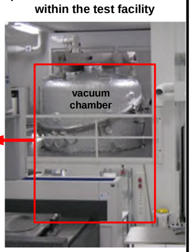


photo of the vacuum chamber within the test facility



Content

Summary and Benefits

Summary

- Max. absorbed heat loads **> 500 W**
- Temperatures **> 700 °C**
- Heat transport mechanisms:
  - heat conduction in solids
  - heat transfer solid / solid
  - heat transfer in a rarefied gas (atmosphere in the EUV-system)
    p < 10 Pa → 0.001 < K_n < 0.1 → continuum with slip flow
  - radiation, view factors and emissivities of all components are taken into account
- Complex model with > 4 million nodes, > 50 structure properties, > 300 interfaces, …
- Transient thermal heat loads for transient thermal simulations.
- Thermal stability in the **µK/min-** and **pm/min-range** of the EUV-system must be guaranteed
  → The image position on wafer level during wafer exposure must be stable.

Summary and Benefits

Benefits

- The results of these transient simulations are an important input to quantify the thermal stability of the EUV-system.
- This information is essential during the layout and detailed design phase.
- The results of the transient thermal simulations help in the design of coolers to prohibit hotspots and thermal drifts.
- With a test facility (vacuum chamber) different scenarios of the optics can be tested.

Thank you

for

your attention

We make it visible.