Micro-Optics: Key Enabling Technology for Advanced Mask Aligner Lithography

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SUSS MicroOptics – We Set The Standards

+ World leading supplier of high-quality Micro-Optics
+ 8” Wafer Technology, Wafer-Level Packaging, SUSS Imprint Lithography
+ More than 200 active customers, e.g. to SEMI equipment manufacturers, Laser & Optics industry, Sensors & Metrology and Medical
+ Part of the SUSS MicroTec Group (www.suss.com)

SUSS MicroOptics is “Preferred Supplier” for Carl Zeiss SMT DUV Laser Beam Shaping Solutions for ASML Litho Stepper
SUSS MicroOptics – 8” Wafer Fab

Cleanroom facility (Class 1 – 1000) for the wafer-based manufacturing of high-quality Micro-Optics

Fully established 8“ technology based on SEMI processes

- 200 mm wafer size (8”)
- Fused silica, Borofloat, Silicon and CaF\textsubscript{2}
- Refractive Microlenses: Spheres, aspheres
- Diffractive Optical Elements (16-level)
- Random diffusers, hybride Micro-Optics

- Double sided arrays, stops, coatings
- Wafer-Level Packaging, Bonding
- Master Lens Arrays for Replication and Imprint Lithography
SUSS MicroOptics’ Solutions

- Refractive Microlens Arrays (ROE)
- Hybrid: ROE + DOE + Posts
- Diffractive Optical Elements (DOE)

- Fiber Coupling
- Microlens Imprint Lithography
- Wafer-Level Camera (WLC)
- Laser Beam Shaping
- Illumination Systems
High-Quality Diffractive Optical Elements (DOE)

- 8" wafer scale
- 190nm to 10μm wavelength range
- 0.5 μm min feature size
- < 50nm overlay accuracy
- Binary, 8-level, 16-level
- SiO₂, Si, CaF₂
- 98% diffraction efficiency demonstrated at 193nm wavelength (16-level DOE)
Hybrid: ROE + DOE + Posts/Trenches + Marks

- Refractive Microlens Arrays
- Diffractive Optical Elements (DOE)
- Deep trenches, posts, grooves, holes
- Random diffusers, alignment marks
- Full integration with excellent lateral precisions on 8" wafer
Micro-Optics Solutions

- Semiconductor Technology
- Industrial Optics & Vision
- Healthcare & Life Science
- Metrology
- Laser & Material Processing
- Information Technology
- Research
High-quality micro-optics
for stepper and mask aligner illumination systems.
Thousands of books and patents on optical lens design
How many books are describing illumination systems?
Illumination is always the “little brother” of the glorious lens design – nobody wants to play with – except if he really has to!
In 1893 August Köhler (1866–1948) from Carl Zeiss in Jena, introduced a new and revolutionary method for uniform illumination of specimen in an optical microscope in his doctoral thesis.

The Köhler method allows to adjust the size and the numerical aperture of the object illumination in a microscope independent from each other.

August Köhler, Zeitschrift für wissenschaftliche Mikroskopie, Band X, Seite 433-440 (1893)
Microlens Optical Integrator (Köhler)

August Köhler

Microlens Array

Flat-Top Intensity Profile
Complex Spatial Filtering with Binary Masks

B. R. Brown and A. W. Lohmann

Usually a hologram is produced by means of an interference experiment. Here, however, we let a computer-guided plotter draw the hologram. The plot, which has to be minified and recorded on film, contains no grey, only binary transmittance values. Our binary holograms yield reconstructed images of a quality equal to that of images obtained from usual holograms of comparable dimensions. When a Fourier hologram is inserted into the Fraunhofer plane of a coherent image forming system, it acts as a special type of a spatial filter, a so-called optical matched filter. Our binary matched filter is suitable for optical character recognition, the same as the usual optical matched filter introduced by Vander Lugt.

Fig. 4. Two matched filters or Fraunhofer holograms for $F$: (a) according to Fig. 3(a); (b) according to Fig. 3(b).

Both authors were with The IBM Corporation, Research Division, San Jose, California 95114. The present address of B. R. Brown is Physics Department, California Institute of Technology, Pasadena, California. Received 10 February 1966.
Micro-Optics in Front-End Lithography

Customized Illumination
Pupil Shaping (DOE)
Now: FlexRay™
programmable illumination
technology from ASML

Excimer Laser (193nm)
Laser Beam Shaping
Laser Beam Homogenizing

Micro-Optics: Key Enabling Technology
in Front-End Lithography
Mask Aligners are the work horse of SEMI industry since the very beginning!
Mask Aligner:

**Technology changed tremendously over the last 40 years**

- 1969: MJB21
- 1985: MA150
- 2010: MA200 Compact

**The Illumination Optics never did!**
Back End Lithography

Mask Aligners Lithography is „Shadow Printing“

+ Mask illumination using UV light
+ Resolution $\leftrightarrow$ proximity gap
Mask Aligners are

+ Mature technology
+ Cost-effective
+ Fast (high throughput)
+ Service friendly
+ Easy to use
+ Convenient
Technology Backbone: Microlens Optical Integrators

- Uniform light distribution
- Uniform angular spectrum

Optical Integrator (I)

Fourier Lens

$f_{FL}$

Optical Integrator (II)

Fourier Plane

Exchangable Illumination Filter Plate (IFP)

Flat-top intensity profile

(Patent pending)
MO Exposure Optics

Library of Illumination Filter Plates (IFP)

MO Exposure Optics (patent pending)

Optical System MA 200

Microlens Array

Microlens Optical Integrators
Better Uniformity – Independent of Lamp Position

Excellent Light Uniformity

+ Independent from lamp misalignment and degradation of lamp electrode during lifetime cycle

Deviation from mean value in [%] for Ø200mm in MA200 Compact

Mean Value 78.0 mW/cm²

Lamp Position: Uncritical

Lamp Tilt: Uncritical

Uniformity 1.0%

-0.5%  
-0.1%  
-0.3%

0.0%  
0.0%  
0.6%

-0.6%  
-0.8%  
-0.6%

-0.6%  
0.0%  
0.0%

0.3%  
0.3%  
0.5%

0.3%  
-0.4%  
1.0%

-0.9%  
-0.9%  
0.1%

-1.0%  
0.1%  
0.1%

8”  
6”  
4”  
3”
MO Exposure Optics: Stabilize the Mask Aligner

Features
+ Stable Light Source
+ Excellent Uniformity
+ Telecentric Illumination

Benefits
+ Reduced Maintenance
+ Improved CD Uniformity
+ Larger Process Window
+ Higher Yield
Customized Illumination

Library of Illumination Filter Plates (IFP)

Micro Optics + Illumination Filter Plate
Customized Illumination - Optimize Pattern

Photomask Pattern
Square 10x10µm²

Prints in Photoresist, 1.2µm thick resist (AZ 4110), 100µm Proximity Gap, SUSS MA8
Optical Proximity Correction (OPC)

Square 10µm x 10µm, Proximity Gap 50µm, Photoresist AZ4110, 1.2µm thick
Expertise in Lithography Simulation

Lithography Simulation
Source-Mask Optimization Service
Research & Technology Partners

Simulation 3D Resist Structure
(Layout Lab, GenISys)

Printed Resist Structure
Talbot Self Imaging in Mask Aligner

From Wikipedia

- The Talbot Effect is a near-field diffraction effect first observed in 1836 by Henry Fox Talbot. When a laterally periodic wave distribution is incident upon a diffraction grating, its image is repeated at regular distances away from the grating plane. The regular distance is called the Talbot Length, and the repeated images are called Self Images or Talbot Images. Furthermore, at half the Talbot length, a self image also occurs, but phase-shifted by half a period. At smaller regular fractions of the Talbot Length, sub-images can also be observed. At one quarter of the Talbot Length, the self image is halved in size, and appears with half the period of the grating. At one eighth of the Talbot length, the period and size of the images is halved again, and so forth creating a pattern of sub images with ever decreasing size.

- Lord Rayleigh showed that the Talbot Effect was a natural consequence of Fresnel Diffraction and that the Talbot Length $z_T$ can be found by the following formula

$$z_T = \frac{2a^2}{\lambda}$$

where $a$ is the period of the diffraction grating and $\lambda$ is the wavelength of the light incident on the grating.

MO Exposure Optics now allows to perfectly shape the illumination in a SUSS Mask Aligner to use Talbot Imaging for printing of periodic structures.
MO Talbot Lithography (Periodic Structures/PSS)

- Hexagons: 3 µm
- Pitch: 5 µm
- Resist: 2 µm thick
- Etching: RIE (Bosch) Silicon
- Proximity Gap: 102 µm
- Mask Aligner: MA8/BA6

5µm

SUSS MicroOptics
MO Talbot Lithography (Periodic Structures/PSS)

- Flowers: 4 µm
- Pitch: 5 µm
- Resist: 2 µm thick
- Etching: RIE (Bosch) Silicon
- Proximity Gap: 102 µm
- Mask Aligner: MA8/BA6

0.8 µm
Examples of Microstructuring in Mask Aligner + SMO

Figure 1. Different realized microstructures: in photo resist (left), etched into silicon (right)

SUSS Mask Aligner MA6
+ MO Exposure Optics
+ Customized Illumination
+ Half-tone photomask*
+ Proximity Litho, Gap 10µm

*T-Half-tone photomask (dot-size 450nm), E-Beam written

**Technology Drivers:**
- System integration
- Device performance
- Cost
- Formfactor

Today’s via sizes: 1-200µm

**Technology Challenges:**
- TSV creation
- Thin wafer handling
- Chip or wafer bonding
- RDL and bumping
- IPD integration

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Fig. 1: Overview on different 3D TSV platforms (a) – 3D WLP Encapsulation, (b) – 3D TSV Stack, (c) – 3D TSV interposer Module, (d) – 3D TSV ground via. 
Source: Market Perspective, Mr. Jean-Christophe Eloy, Yole Développement, in 3D IC Technology Forum at SEMICON Taiwan, September 9, 2010
New Thin Si Wafer Technology: Taiko Wafer

+ Taiko Wafer Concept
  → Carrierless Thin Wafer Technology

Requires outstanding optical performance for extreme large exposure gaps for TSV etch mask litho and RDL

→ MO Exposure Optics + Source Mask Optimization

Courtesy: Doublecheck semiconductors
200mm Taiko wafer, Thickness 50µm
Focus: Packaging, 3D IC and TSV

Illumination Filter Plates (IFP)

OPC Structure (Fresnel-type)

11µm via at 800 µm proximity gap

Resulting Aerial Image

Depth of focus (DOF)
Focus: Packaging, 3D IC and TSV

Benefits

- Very large proximity gap
- Via shaping possible
- Extended Depth of Focus (DOF)
- Very short exposure time (focussing)

![Side view of 3D IC and TSV with DOF](image)

<table>
<thead>
<tr>
<th>Gap (µm)</th>
<th>Ø Via (µm)</th>
<th>DOF (µm)</th>
</tr>
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<tbody>
<tr>
<td>100</td>
<td>2</td>
<td>5</td>
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<tr>
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<td>100</td>
</tr>
<tr>
<td>700</td>
<td>14</td>
<td>200</td>
</tr>
</tbody>
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Typical parameters for via printing using OPC Fresnel Technology
A Mask Aligner is a Mask Aligner is a Mask Aligner!

Yes! But...
Quick wins
+ Improved CD uniformity
+ Higher throughput
+ Less downtime

New process parameter: Illumination!
+ Customized illumination
+ Optical Proximity Correction (OPC)
Available for all SUSS Mask Aligners

MA6, MA8

MA/BA8 Gen3

MA200Compact, MA100e, MA150e

LithoPack 300

MA300 Gen2

MJB4
SUSS.

Our Solutions
Set Standards

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