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Yield improvement in microlens imprint lithography (SMILE) by artificial intelligence

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SUSS MicroOptics is part of the* ***SUSS MicroTec* *group*

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PHOTONICS-WORKSHOP: «ARTIFICIAL INTELLIGENCE IN PHOTONICS»

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PHOTONICS

- The term **Photonics*** was introduced in 1967 by Pierre Aigrain (1924-2002), a French scientist. In 1973* he claimed: "I believe, that tomorrow, that is to say in 1990, photonics will play an important part in the transmission of information ... Photonics is a technology of tomorrow.“
- Photonics was the compromise when classical optics industry merged with laser industry.
- **Wikipedia 2019[**]: "Photonics** is the physical science of light (photon) generation, detection, and manipulation through emission, transmission, modulation, signal processing, switching, amplification, and sensing."
- **Photonics market segments:** LED, Lasers, Detectors, Sensors, Imaging, Displays, Optical Communication, Components, Media Technology, Lighting, Photovoltaics, …

Pierre Aigrain (1924-2002)

[*] https://www.laserfocusworld.com/blogs/article/16564148/photonicswhats-in-a-name
[**] Chai Yeh (2 December 2012). Applied Photonics. Elsevier. pp. 1–. ISBN 978-0-08-049926-0

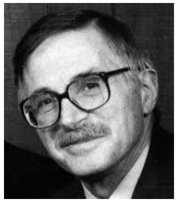
SEMI: Key to Success is Wafer Manufacturing

1947: Invention of the transistor by John Bardeen, William B. Shockley and Walter H. Brattain (1956: Nobel Price)

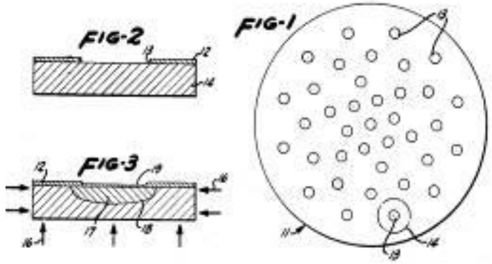
1955: Shockley Semiconductor Laboratory

1957: The “Traitorous Eight” split from Shockley and start Fairchild Semiconductor: Robert Noyce, Gordon Moore, **Jean Hoerni**, Eugene Kleiner, Julius Blank, Sheldon Roberts, Jay Last, and Victor Grinich.

1959: Jean Hoerni invents the “parallel process". Wafer manufacturing is the key to success for semiconductor industry!

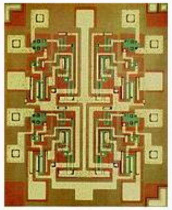


Jean A. Hoerni
(1924-1997)



"Wafer"

Semiconductor manufacturing processes



10 µm – 1971
6 µm – 1974
3 µm – 1977
1.5 µm – 1981
1 µm – 1984
800 nm – 1987
600 nm – 1990
350 nm – 1994
250 nm – 1996
180 nm – 1999
130 nm – 2001
90 nm – 2003
65 nm – 2005
45 nm – 2007
32 nm – 2009
22 nm – 2012
14 nm – 2014
10 nm – 2016
7 nm – 2018
5 nm – 2019
3 nm – ~2021

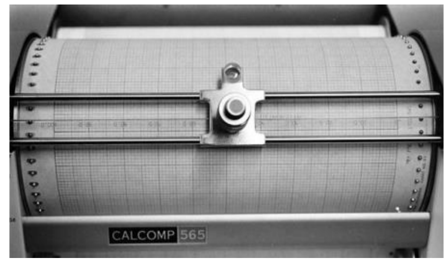
https://en.wikipedia.org/wiki/Semiconductor_device_fabrication

Computer Generated Holograms (CGH)

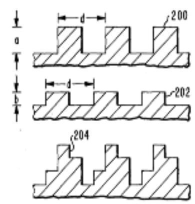
Fig. 7.7. Adolf Lohmann (centre) with Byron Brown and Ronald Kay of IBM, c.1966 (Lohmann collection)

Fig. 7.8. Computer-generated binary hologram and its reconstruction, Lohmann et al., 1967 (Lohmann collection)

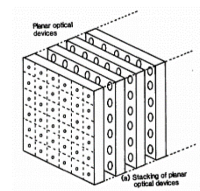
Source: A. W. Lohmann



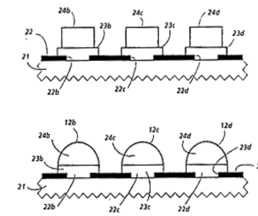
CALCOMP 565 Plotter



Multi-Level DOE



Stacked planar micro-optics



Melting resist microlenses

- 1966 **Digital** or **Planar Optics**
- 1977 Mike Gale: multi-level **diffractive optics**
- 1982 Kenichi Iga: **stack**ed planar optics
- 1985 Zoran Popovich: melting resist **microlens**es
- 1986 Adolf Lohmann*: "Electronic Computers reached fundamental limits and can't get much faster anymore. We urgently need to get **Optical Computers**"

COMPUTERWOCHE

Hinter den Kulissen wird unbeirrt am optischen Computer gearbeitet:

Bald geht den Rechenzentren ein Licht auf

24.10.1986

[*] My first optics lecture on Nov 6th, 1986 at University of Erlangen Nürnberg

SUSS MICROOPTICS – WE SET THE STANDARDS

+ World leading supplier of high-quality Micro-Optics
+ More than 200 active customers worldwide
+ We are part of **SUSS MicroTec** group

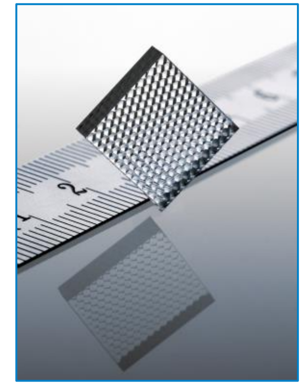
20 Years

of Micro-Optics FAB Experience

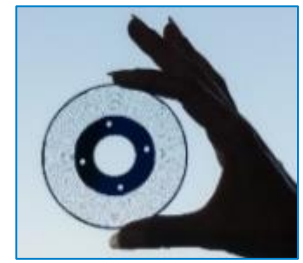
IATF 16949

Automotive Qualified

8'' Wafer Cleanroom Fab



Microlens Array



Nipkow Disk

MO Exposure Optics

BUSINESS DEVELOPMENT

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- Strong growth in Niche Markets
- 2012: New Cleanroom Fab @Innoparc I
- 2018: New production line for Automotive Lighting
- 2019: 2nd Cleanroom Fab @Innoparc IV

20 Years
of Micro-Optics FAB Experience

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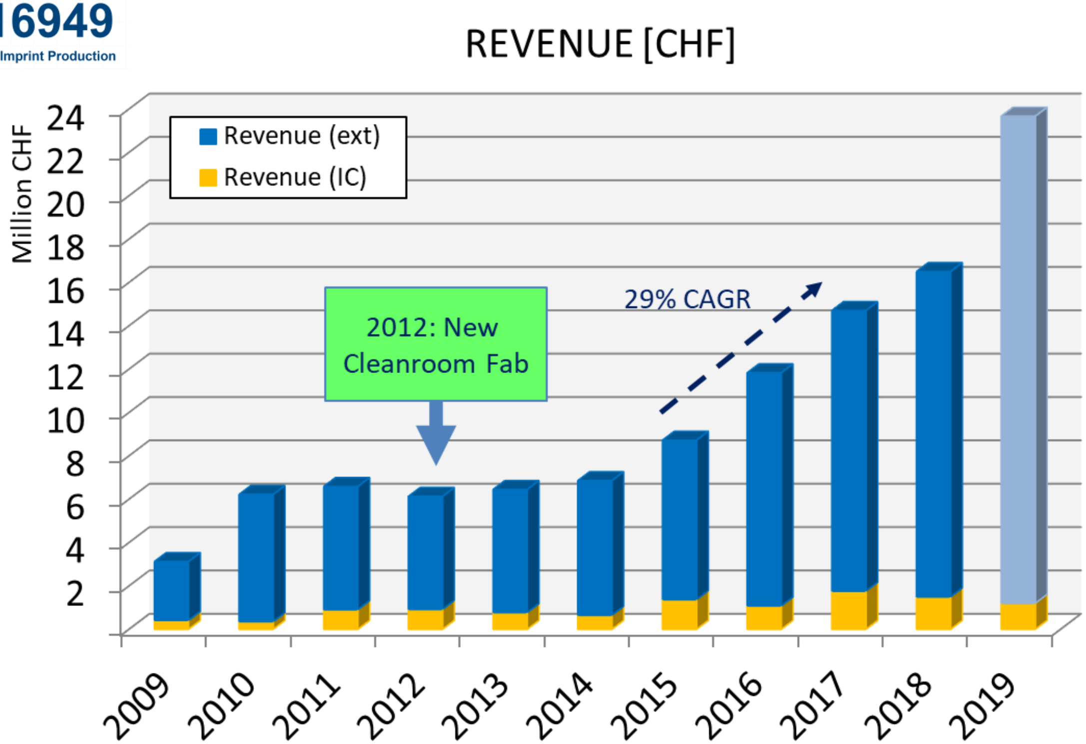
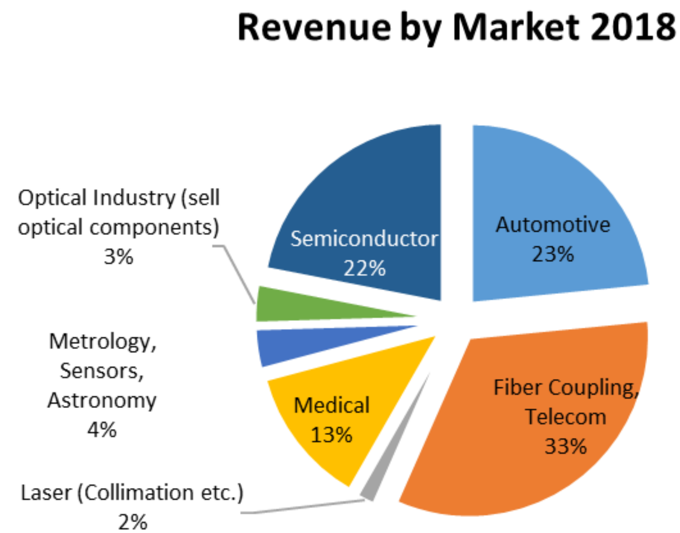
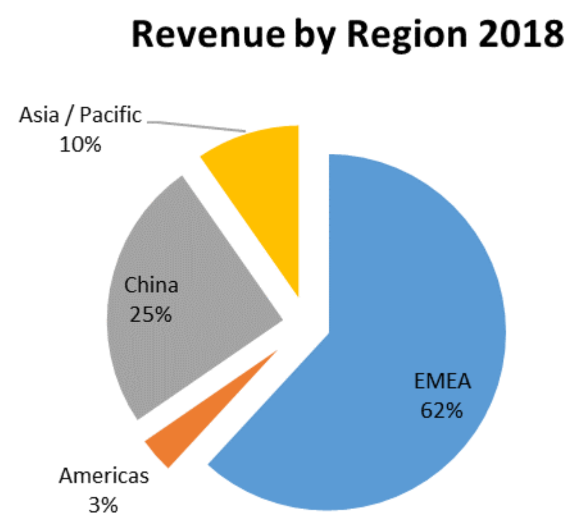
Automotive Qualified Imprint Production







SEMI VERSUS PHOTONICS

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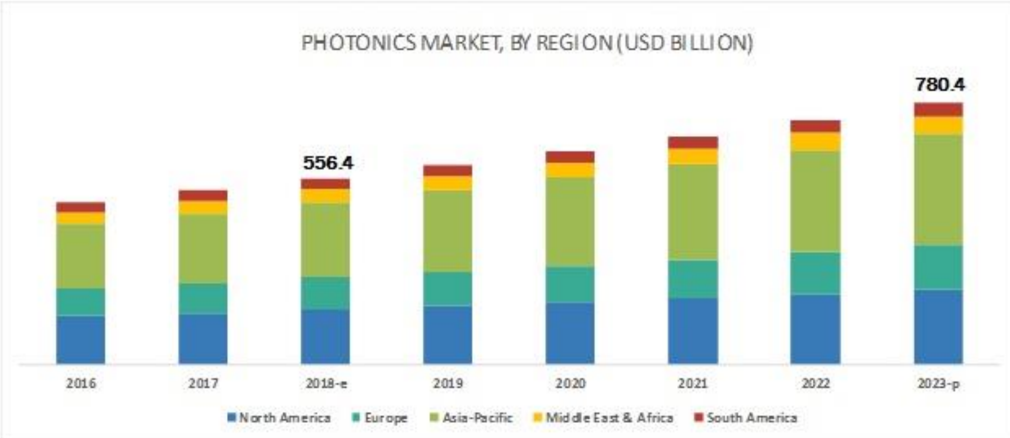
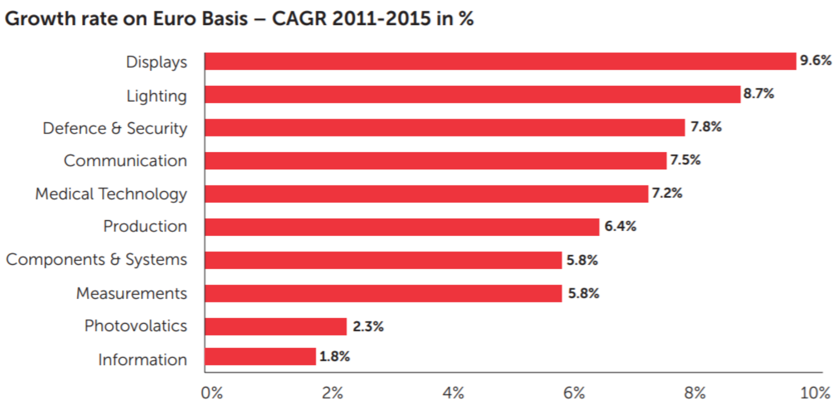
+ Global semiconductor revenue was $477* billion in 2018
+ Global photonics revenue was $556** to $640*** billion in 2018



Kennzahlen Photonik Schweiz 2017



2018 Rank	2017 Rank	Vendor	2018 Revenue	2018 Market Share (%)	2017 Revenue	2017-2018 Growth (%)
1	1	Samsung Electronics	75,854	15.9	59,875	26.7
2	2	Intel	65,862	13.8	58,725	12.2
3	3	SK hynix	36,433	7.6	26,370	38.2
4	4	Micron Technology	30,641	6.4	22,895	33.8
5	6	Broadcom	16,544	3.5	15,405	7.4
6	5	Qualcomm	15,380	3.2	16,099	-4.5
7	7	Texas Instruments	14,767	3.1	13,506	9.3
8	9	Western Digital	9,321	2.0	9,159	1.8
9	11	ST Microelectronics	9,276	1.9	8,031	15.5
10	10	NXP Semiconductors	9,010	1.9	8,750	3.0
		Top-10	**283,088**	**79.3**	**238,815**	**18.5**
		Others (outside top 10)	**193,605**	**20.7**	**181,578**	**6.6**
		Total Market	**476,693**	**100.0**	**420,393**	**13.4**

Source: Gartner (January 2019)

[*] https://www.gartner.com/en/newsroom/press-releases/2019-04-10
[**] https://www.marketsandmarkets.com/Market-Reports/photonics-market-88194993.htm
[***] https://www.mordorintelligence.com/industry-reports/photonics-market-market

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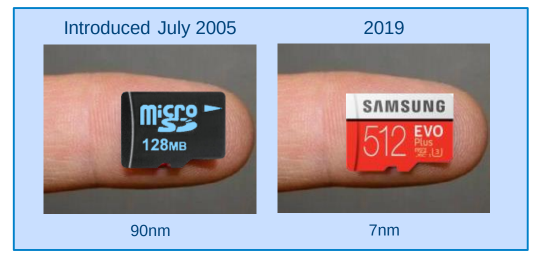
What are the big differences between Photonics and Semiconductor Industry?

SEMI

- Wafer-based manufacturing using Ø200mm and Ø300mm wafers
- High degree of standardization and automatization
- Highly parallel manufacturing processes
- Standardized manufacturing equipment ($65 billion annual spending)
- Price reduction of 30% per year since 1960 for logic and memory



PHOTONICS

- Mostly manual processes and one-piece flow manufacturing
- Fewer standardization and high diversity
- Wafer-based manufacturing is < 15% of the global Photonics revenue
- Often low automatization makes up-scaling a challenge

THE NEXT BIG THING FOR SEMI IS ARTIFICIAL INTELLIGENCE

What does this mean for Photonics?

THE NEXT BIG THING IS ARTIFICIAL INTELLIGENCE (AI)

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Market Research Future*

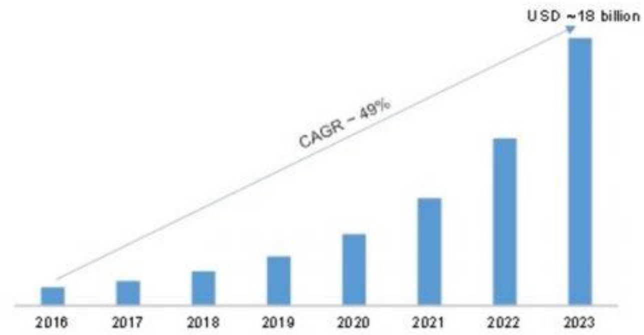
+ "Global Artificial Intelligence (AI) chipset market will grow 2018 to 2023 at 31% CAGR and reach more than $16 billion by 2023."

Forbes**

+ "AI and machine learning have the potential to create an additional $2.6T in value by 2020 in Marketing and Sales, and up to $2T in manufacturing and supply chain planning."

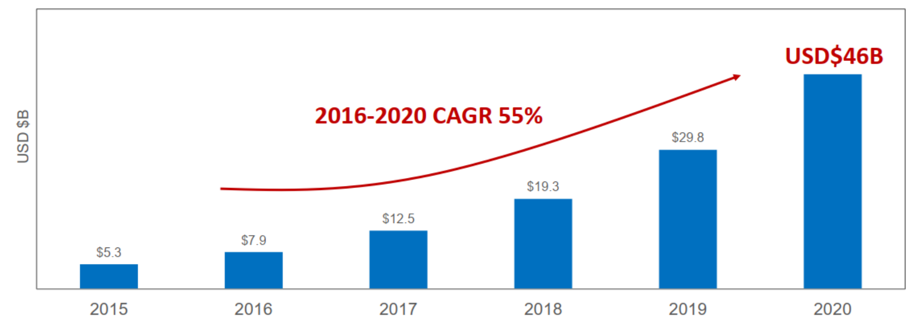
Gartner***

+ Business value created by AI will reach $3.9T in 2022.

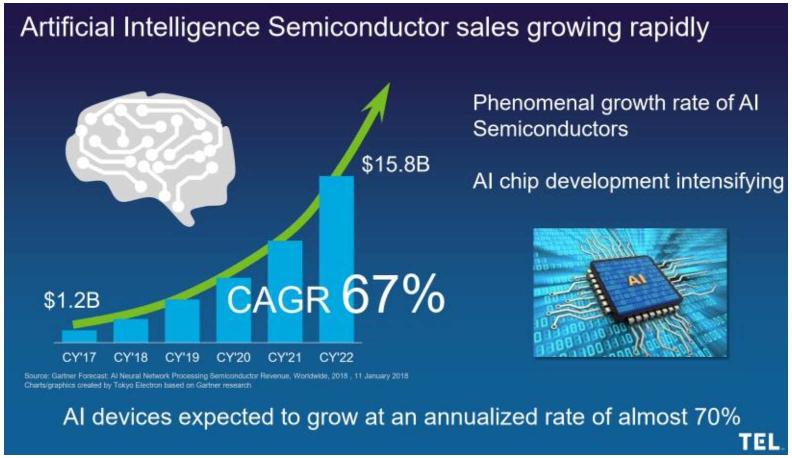


AI chipset market growth by Market Research Future*

Worldwide spending on cognitive and AI systems



Source: IDC Cognitive/AI Spending Guide 2017



Artificial Intelligence Semiconductor Sales by TEL at SEMI Taiwan 2018***

[*] https://www.marketresearchfuture.com/reports/artificial-intelligence-chipset-market-4987
[**] http://Akihisa SEKIGUCHI, Tokyo Electron Limited talk at SEMI Taiwan IC Forum 2018
[***] https://www.forbes.com/sites/louiscolumbus/2019/03/27

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IT THIS HYPE REAL?
WHAT DOES IT MEAN FOR PHOTONICS?

IS ARTIFICIAL INTELLIGENCE (AI) ALSO THE NEXT BIG THING FOR PHOTONICS?

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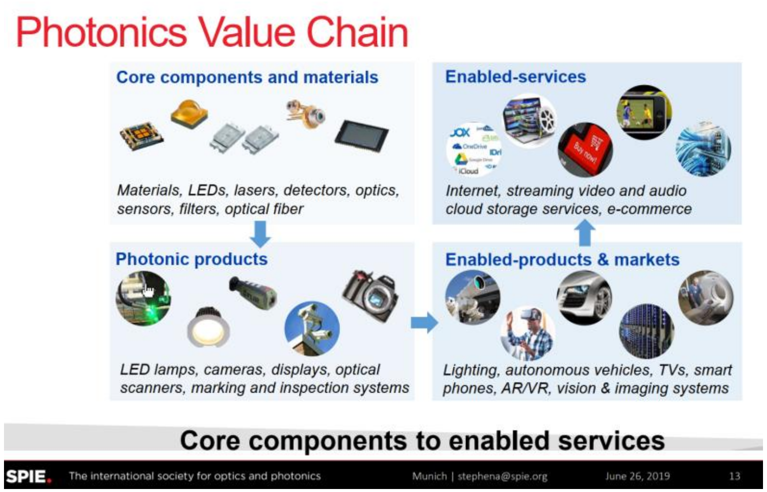
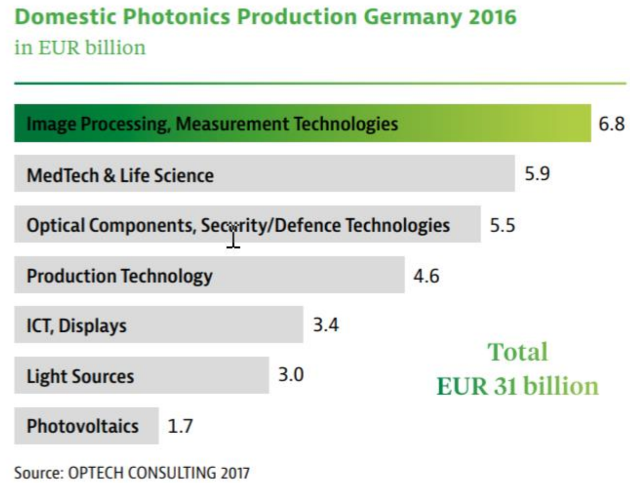
- SEMI and Software will get the major part of the cake!
- Classical Photonics companies will profit <u>indirectly</u> as AI will further generate the need for more
  - Sensors, cameras, LiDAR, metrology, …
  - Communication, fiber optics, optical switches, data center, …
  - Lasers, VCSEL, LED, displays, …
- Production equipment for SEMI manufacturing (stepper, lithography, laser, …)
- Optical computing, quantum computers?
- Low-hanging fruits: **Yield improvement in wafer-based manufacturing for Semiconductor AND Photonics industry!**





IMPROVE YIELD IN SEMI AND PHOTONICS PRODUCTION

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- **YIELD:** "The proportion of devices on the wafer found to perform properly is referred to as the yield. Manufacturers are typically secretive about their yields, but it can be as low as 30%. **Process variation** is one among many reasons for low yield."
- **SEMI foundries** use AI tools to combine equipment know-how and manufacturing statistics in managing massive **Fault Detection (FD)** data.
- AI enables the **real-time collection** and **monitoring** of massive amounts of processing data and **alerts** system administrators of any hardware failures or other manufacturing abnormalities.
- AI also makes it possible to adopt **Run-to-Run** (R2R) control to automate **manufacturing process adjustments** and **corrections** by providing feedback that can drive higher processing efficiency.
- Supporting the customer to improve the yield in production is a MUST for all **SEMI equipment manufacturers**:

+ AI READY!

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		Total Market	**476,693**	**100.0**	**420,393**	**13.4**

Source: Gartner (January 2019)

PRODUCT PORTFOLIO FOR SUSS MICROTEC

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Equipment for Wafer-Based Manufacturing: SEMI, Photonics, MEMS, …

Frontend | **Mid- und Backend**

Photomask-Equipment	Lithography			Bonder
Photomask Processing	Laser Equipment	Exposure-systems	Coater and Developer	Wafer Bonder
 MaskTrack*Pro*	 ELP300 Gen2	 Mask Aligner MA200 / MA300  Projection Scanner DSC300 Gen2	 ACS300 Gen3	 XBC300 Gen2  XBS200

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MICROLENS IMPRINT LITHOGRAPHY AS AN EXAMPLE FOR ARTIFICIAL INTELLIGENCE IN PHOTONICS

Wafer-Level Photonics

1997 MICROLENS IMPRINT - SUSS MASK ALIGNER

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+ CSEM Zurich (Mike Gale)

Figure 5. UV-embossed sol-gel micro-optics. (a) Modified mask aligner (SUSS, MicroTec Lithography, Germany) for combined UV embossing and lithography of sol-gel materials. Instead of a chrome mask, a special mold is used to emboss a surface microstructure into the sol-gel film on a glass substrate. (b) Replicated sol-gel micro-optical elements.

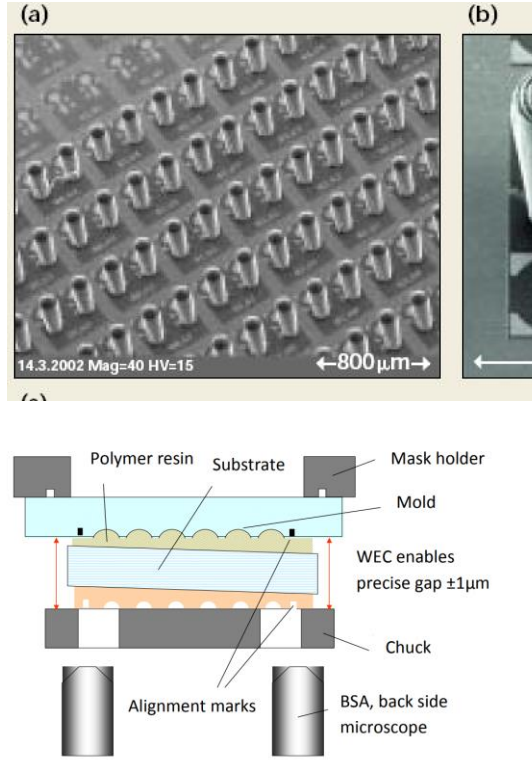

Figure 6. Wafer scale UV embossing of sol-gel components. (a) and (b) Replicated sol-gel microlenses on a VCSEL device wafer. The lenslets couple light from the VCSEL into an optical fiber. [Courtesy of Avalon Photonics, Zurich, Switzerland.] (c) Replicated sol-gel alignment microstructures for optical components. [Courtesy of Leica Geosystems, Heerbrugg, Switzerland.]

M.T. Gale, "Replication," Chapter 6 in Micro-Optics: Elements, Systems and Applications, H.P. Herzig, Ed., Taylor and Francis, London (1997).

Brite-Euram Project BE97-464 1, DONDODEM, Development of new dielectric and optical materials and process-technologies for low cost electrical and/or optical packaging and testing of precompetitive demonstrators, (1998-2001).

WELCOME LIGHT CARPET FOR CARS

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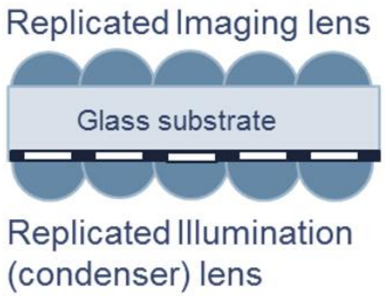

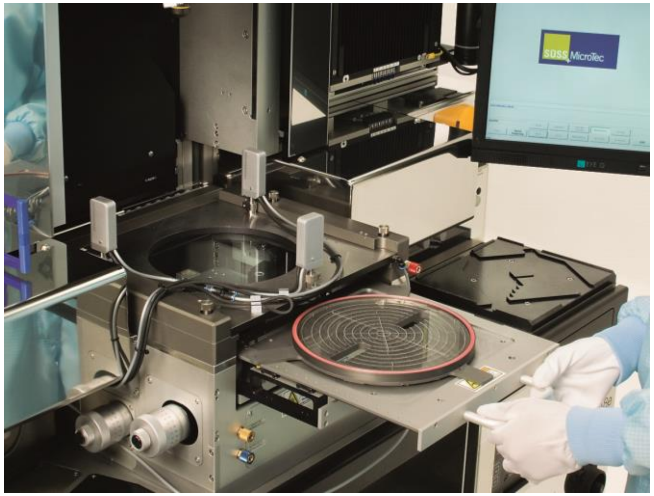

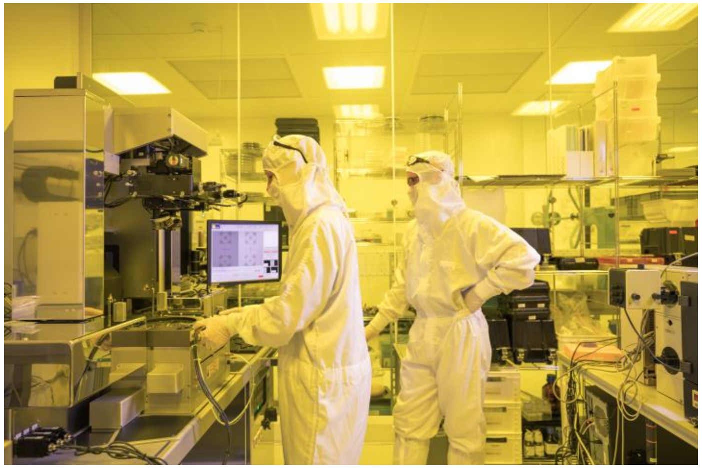

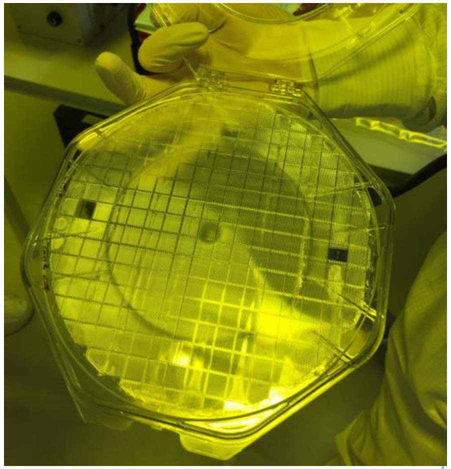

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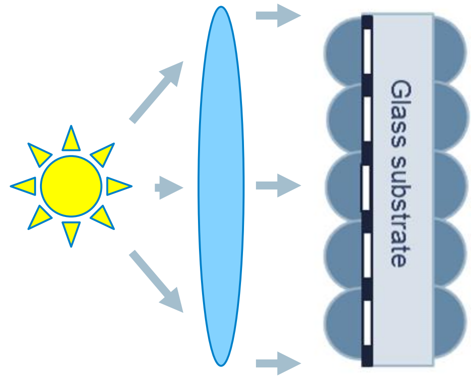
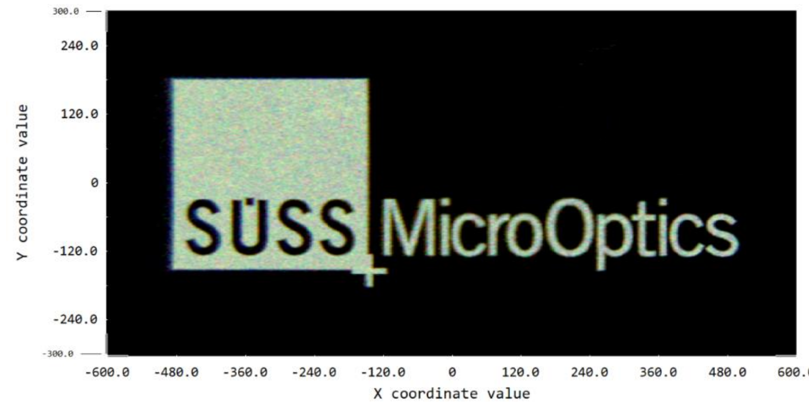
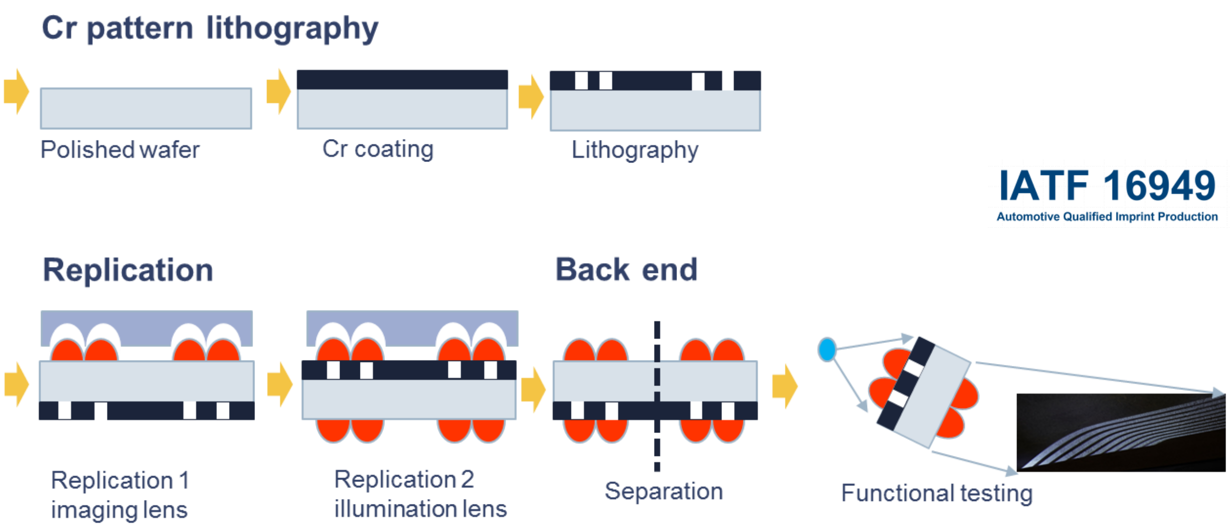
MICROLENS IMPRINT LITHO FOR LIGHT CARPETS



Array Projector (Moiré Magnifier)



Superposition of Microlens Array Projection on Target (Simulation SMO)



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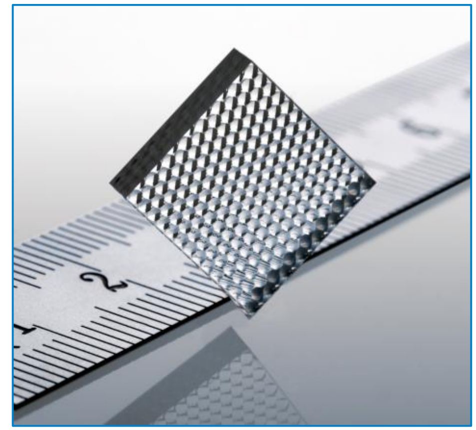

Microlens Array (MLA) for Light Carpets

QUALITY CONTROL FOR IMPRINTED MLA

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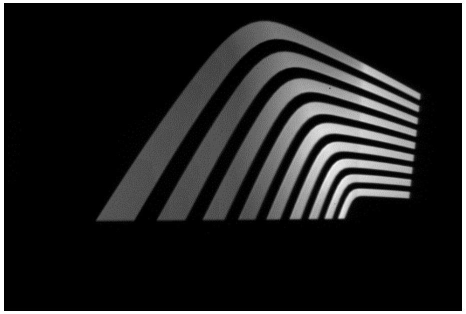
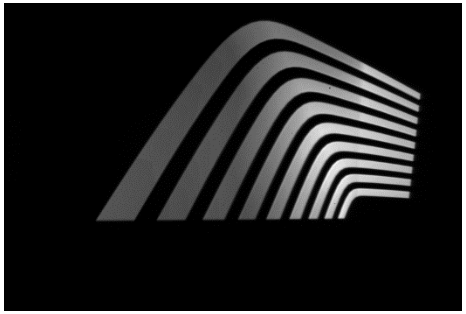
+ Classic rule-based sorting

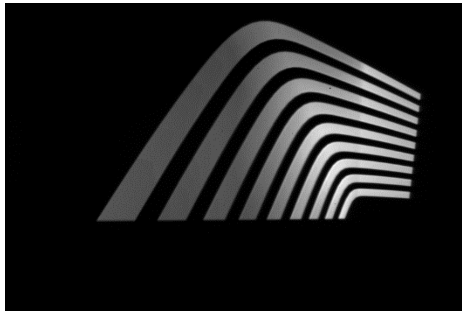
Check Rule 1



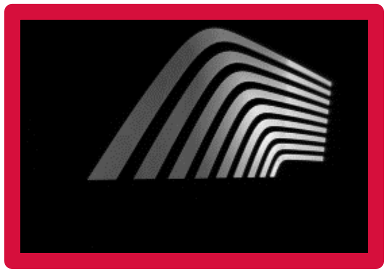
Check Rule 2



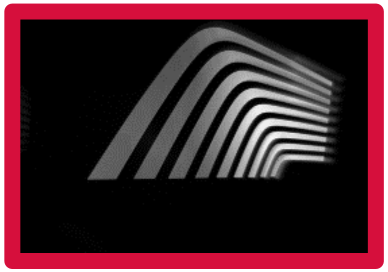
Check Rule 3



Good



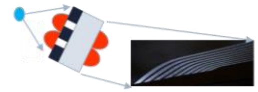
Error 1



Error 2

Error 3

UTILIZE DEEP LEARNING ON PROOF BOX IMAGES



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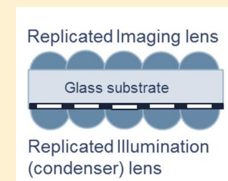
Input

? ? ?

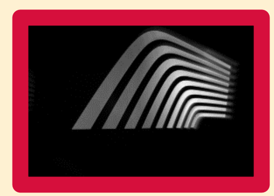
Output

OK

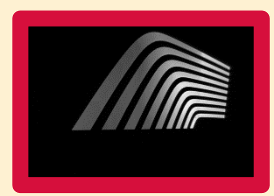


Defective

Class 1
- → Proof Box issue
- → Adjust setup and repeat



Class 2
- → Blurry pattern
- → Root cause: e.g. lens shape
- → Action: e.g. stamp too old



Class 3
- → Issue 3
- → Increase x in process step y

IMAGE SHARPNESS AS QUALITY FEATURE

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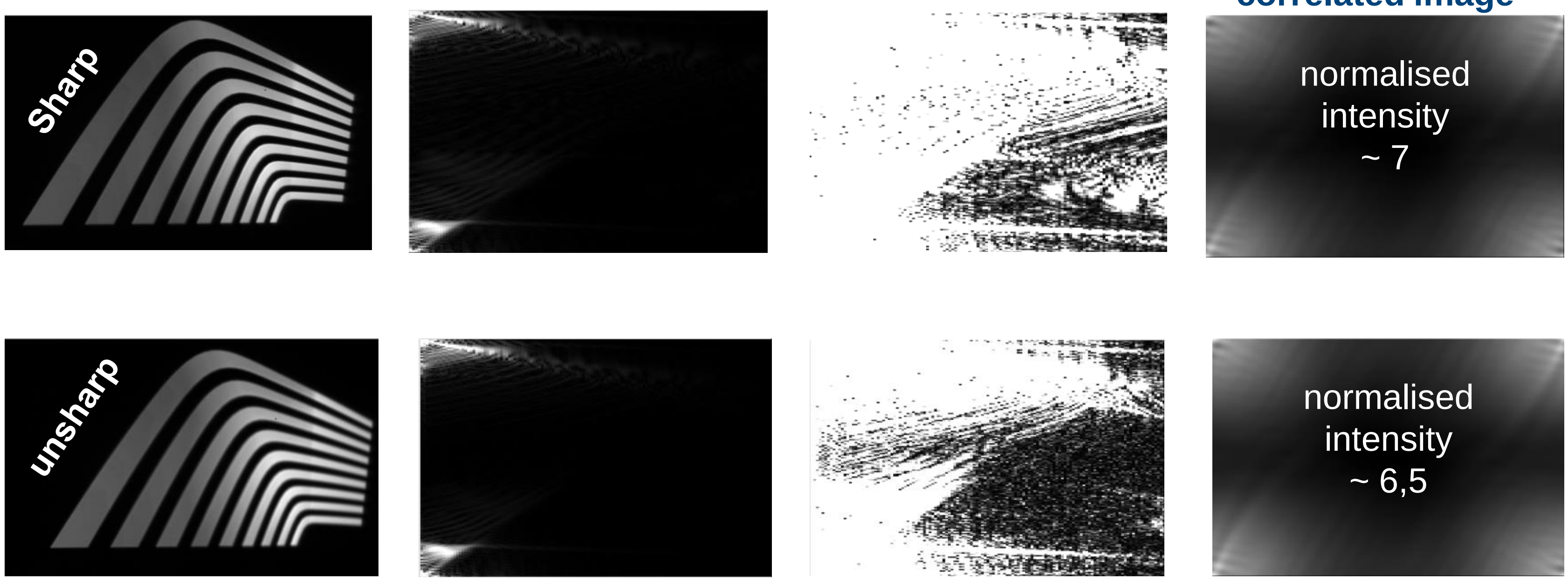
- **Sharpness measure via autocorrelation**
- **Idea: Determine sharpness based in the full image with comparable values for each image**

Original Image | **FFT of the full image** | **Autocorrelation image** | **RFT of the auto - correlated image**



IMPROVE YIELD ON IMPRINT LITHOGRAPHY PROCESS

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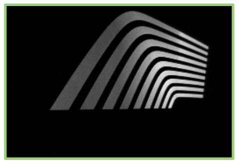
Specification

OK

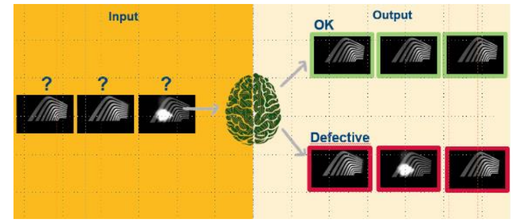


Defect

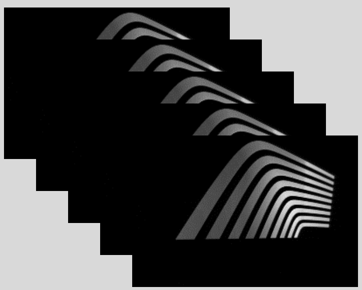
Data Transfer & Annotation

Class 1 Class 2 Class 3

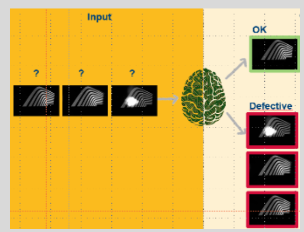
Algorithm Prototype



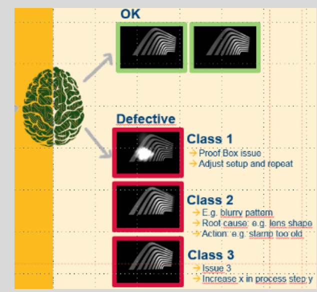
Data Acquisition

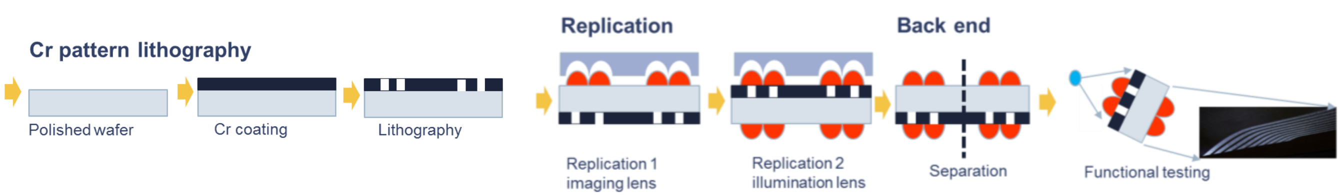


Algorithm Optimization



Correlation to Process





EVOLUTION OF SUSS IMPRINT EQUIPMENT

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Mask & Bond Alignment

Nano-Imprint Lithography

Micro-Imprint Lithography

WLO Stacking

SUSS MicroOptics

7-8 November 2019

EPIC Meeting on Wafer Level Optics at SUSS MicroOptics

Neuchatel, Switzerland

Registration open