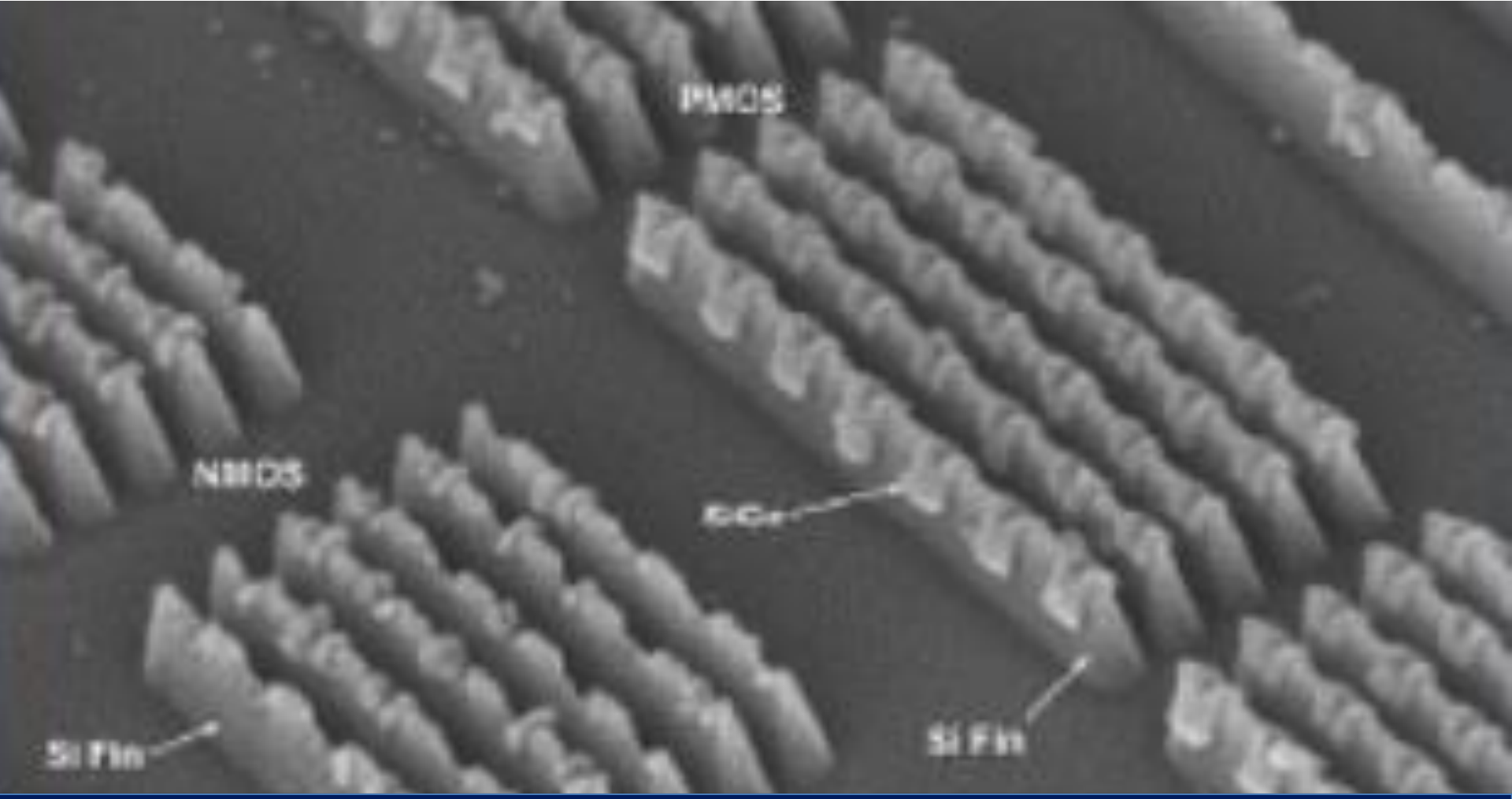


Sub-Wavelength Holographic Lithography

Vadim Rakhovskiy
rakhvi@nanonech-swhl.com

Nanotech SWHL GmbH
www.nanotech-swhl.com

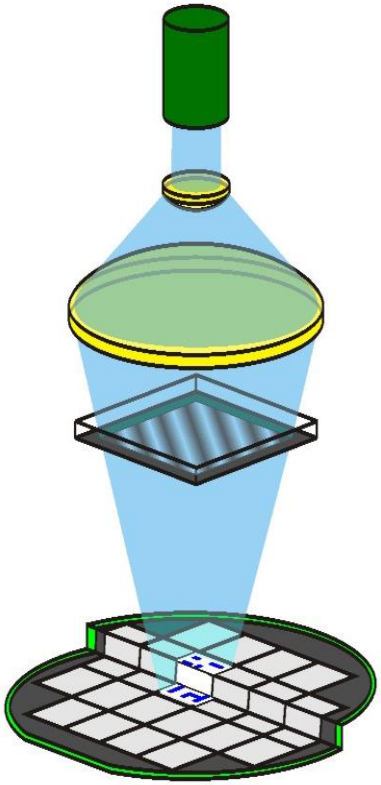
1 SUB-WAVELENGTH HOLOGRAPHIC LITHOGRAPHY - SWHL

- Revolutionary photolithography technology - takes advantage of light diffraction nature to create images
- Based on unique mathematical apparatus able to calculate holographic masks for images with sub-wavelength resolution
- Generates images not possible with traditional projection lithography:
  - Images on multi-level planes spaced at distances much larger DoF with sub-wavelength resolution at one exposure
  - Topologies which are impossible to generate by projection lithography at the same NA and λ
- Offers much lower cost of ownership

2 SWHL – KEY TECHICAL FEATURES

- Optical train of holographic stepper is very simple – slide 4
- Holographic mask has simple structure with relatively large CD's – slide 5
- No need for regular mask control and maintenance - images practically not sensitive to mask local defects – slide 6
- Complicated and expensive technological OPC, Phase-Shift and SMO are performed only virtually during mask calculation – slide 7

2.1 OPTICAL TRAIN OF HOLOGRAPHIC STEPPER IS MUCH SIMPLER



Illuminator
Very simple and less expensive (4x)

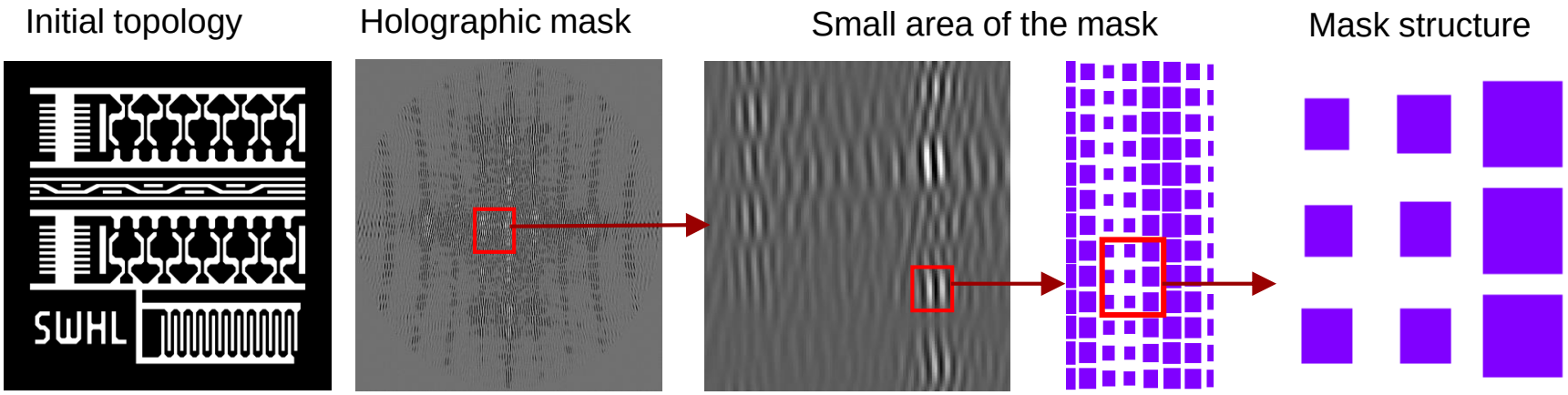
Holographic mask
simple and less expensive (10x)

No projection lens
Holographic mask works as a mask and as a projection lens.

Planar and 3D images

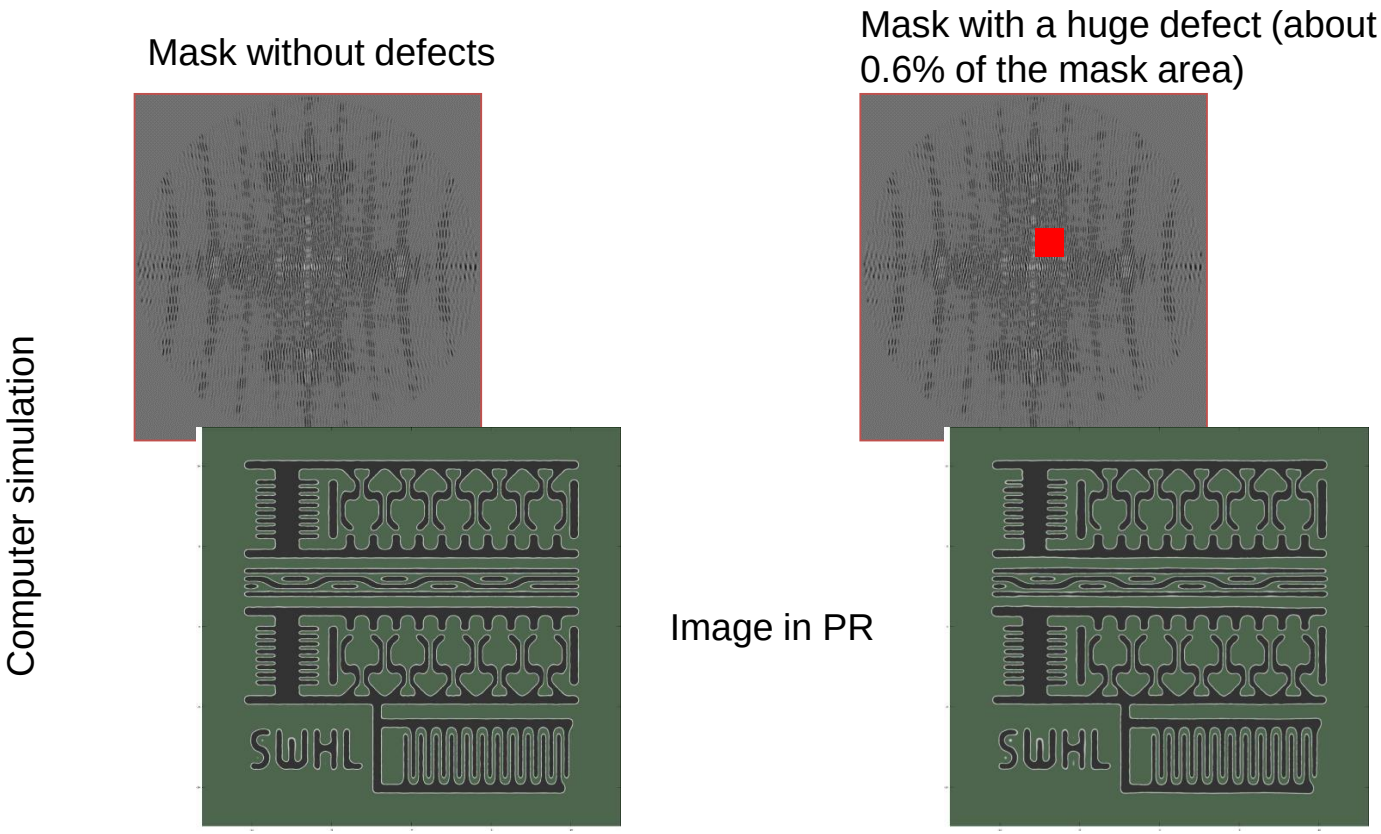
- It uses much simpler mask illuminator and does not use any projection lens which in DUVL/EUV is complex and extremely expensive
- SWHL imposes much softer requirements on quality of optical system because most of light wave aberrations caused by optical elements are taken into account during mask calculation
- Holographic stepper is much less expensive than projection stepper/scanner.

2.2 HOLOGRAPHIC MASK HAS VERY SIMPLE STRUCTURE



- Holographic masks are manufactured by conventional mask manufacturing technology
- They consist of simple uniform elements of relatively large size - up to 15 times larger than elements of projection mask at the same wavelength
- Holographic masks are much simpler and much less expensive - cost of holographic mask - $20k for any node
- Complexity of holographic masks does not increase with resolution.

2.3 HOLOGRAPHIC MASK IS NOT SENSITIVE TO LOCAL DEFECTS



The holographic mask is much less sensitive to local defects and particles (by a factor of 10^9- 10^{10}) compared to projection masks.

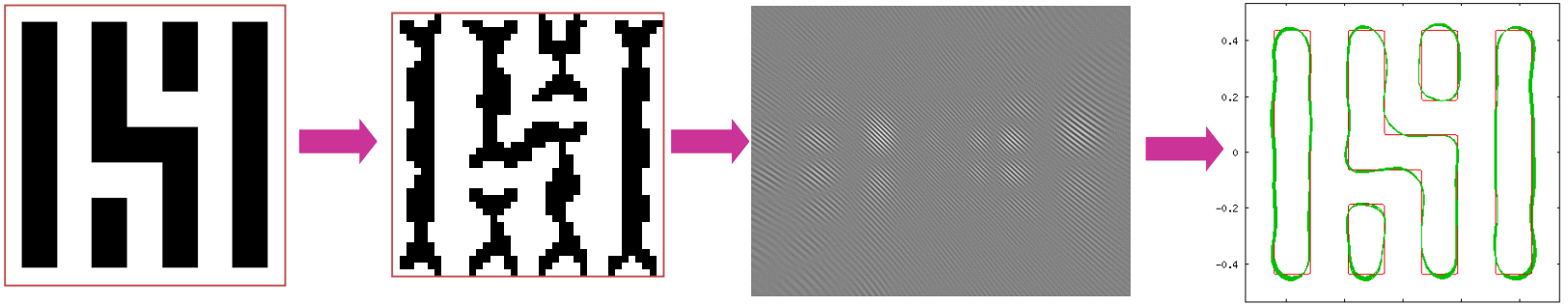
They do not require regular control, maintenance and repair, and have very long lifetime.

2.4 HoloOPC & HoloPHASE-SHIFT ARE VIRTUAL

Holographic mask correction techniques, equivalent to OPC and Phase-Shift, are implemented during mask computing, as opposed to common projection masks, that need labor-intensive and expensive technological procedures

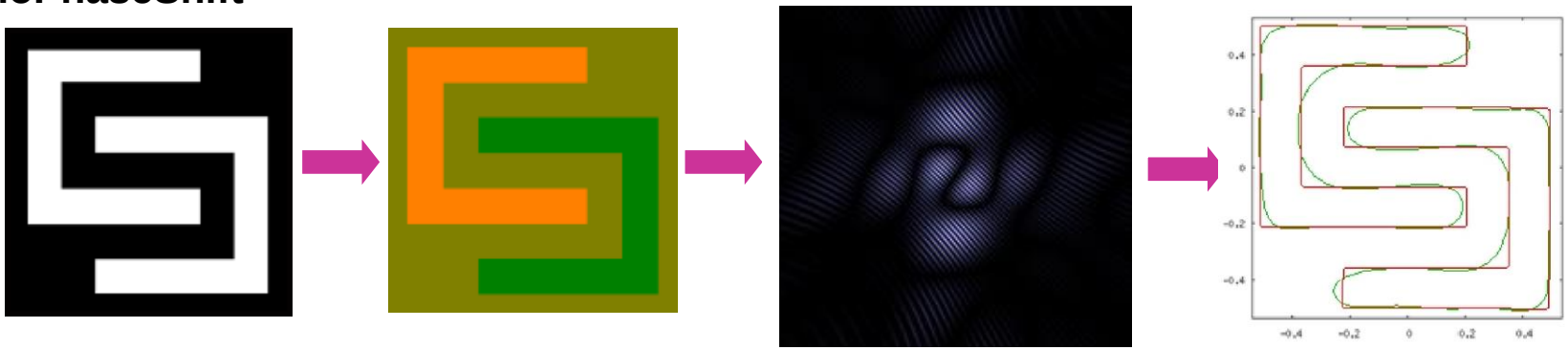
Computer simulation

HoloOPC



Original topology | Vitrtual HoloOPC | Holographic Mask | Recovered image

HoloPhaseShift



Original topology | Vitrtual HoloPhase-Shift | Holographic Mask | Recovered image

3 SWHL – KEY BENEFITS FOR CUSTOMERS

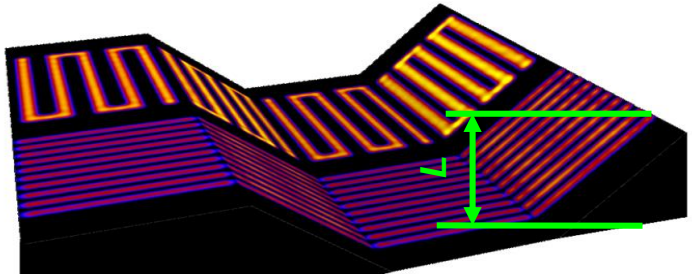
- Possibility to generate images not possible with traditional projection lithography:
  - Images on multi-level planes spaced at distances much larger then DoF – slide 9
  - Continuous Phase-Shift – slide 10
  - Light nail – slide 11

- Much lower initial investments and cost of ownership:
  - Holographic stepper much simpler and less expensive
  - Simple and inexpensive holographic mask
  - No need for mask maintenance, control and repair

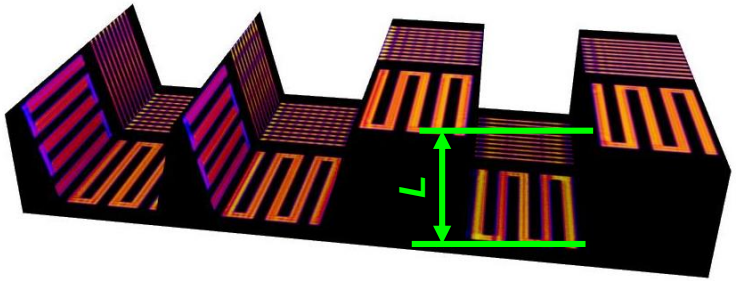
3.1 3D STRUCTURES

Holographic mask are able to create images on multi-level planes with a SINGLE mask during a SINGLE exposure – with the planes located at a distance MUCH MORE than the DoF

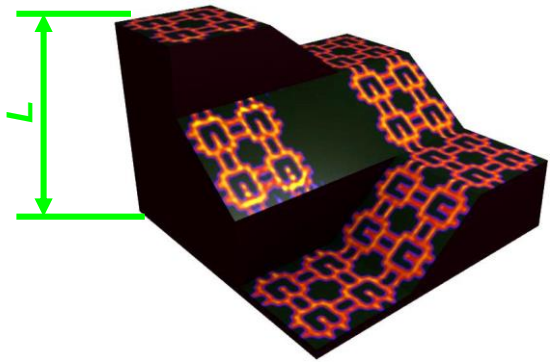
Computer simulation



λ = 375 nm, NA = 0.8,
half-pitch: 200 nm & 400 nm
L = 2.8μ, Rayleigh *DoF* = ± 0.44μ



λ = 355 nm, NA = 0.8,
CD = 400 nm,
L = 9.6μ, Rayleigh *DoF* = ± 0.44μ



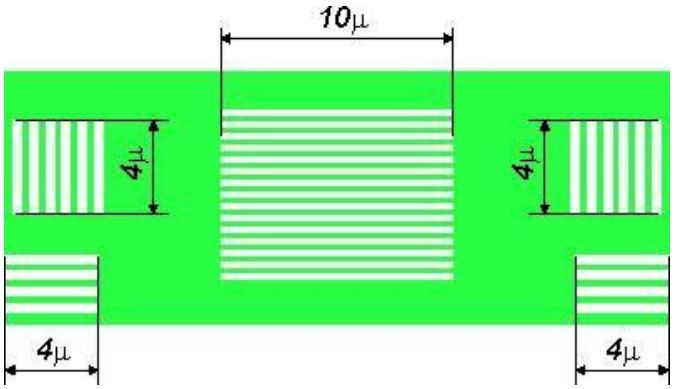
λ = 375 nm, NA = 0.65,
half-pitch: 400 nm & 800 nm
L = 8μ, Rayleigh *DoF* = ± 0.34μ

4 TECHNOLOGY DEVELOPMENT MILESTONES UP TO DATE

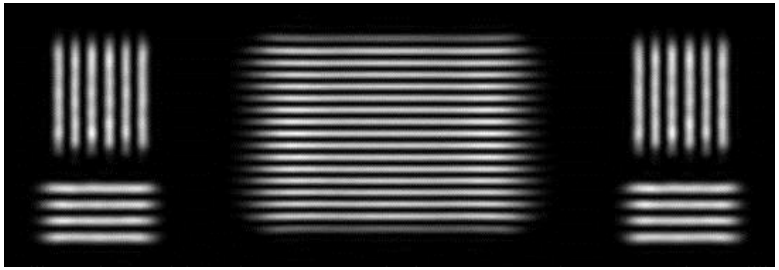
- Physical concept of SWHL proven theoretically
- Produced small images with **sub-wavelength resolution** on photoresist – slide 13
- Designed and manufactured experimental Holographic Tool - slide 14
- Produced **larger flat images** and **3D images at one exposure** - slides 15 and 16
- 4 RF Patents and 3 US Patent received for the technology; 1 US Patent approved; 2 US patent applications pending

4.1 IMAGE WITH SUB-WAVELENGTH RESOLUTION

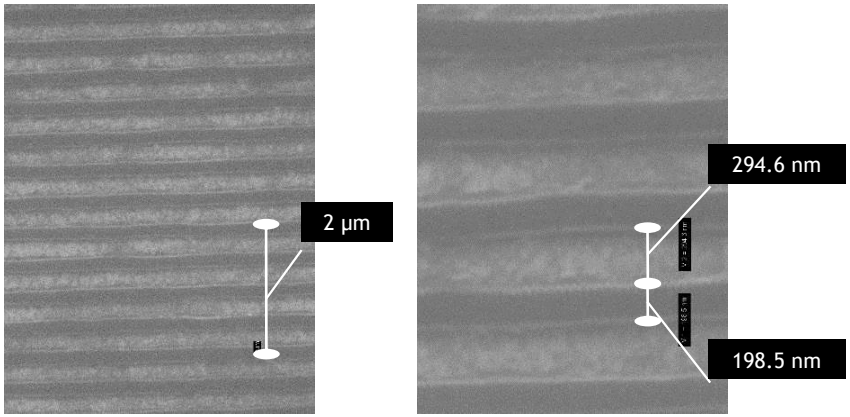
Initial topology



Aerial image
(computer simulation)



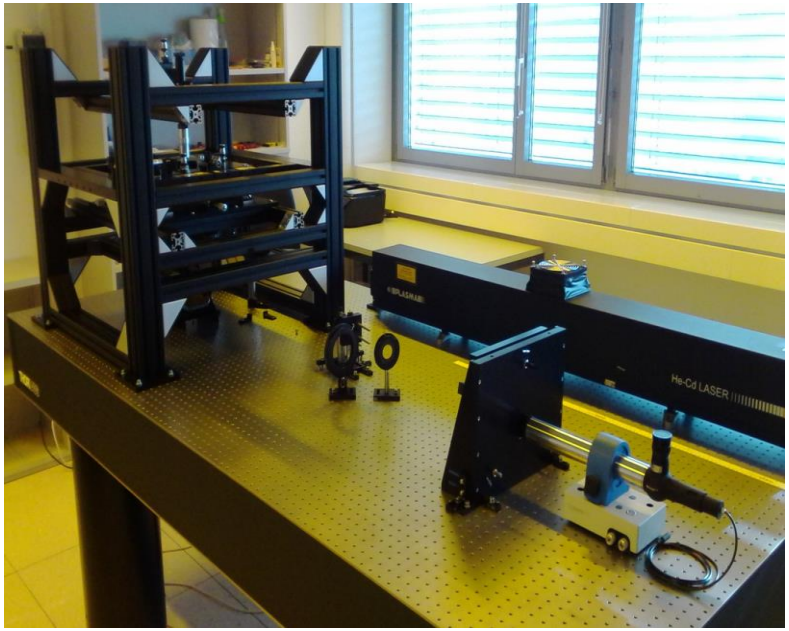
Photoresist
SEM image inspection



The experimental results demonstrated that SWHL produces **images with sub-wavelength resolution**:

- Wave-length 441.6 nm
- Image resolution 247 nm (0.56λ)
- Image size 50 um
- NA = 0.53

4.2 FIRST EXPERIMENTAL HOLOGRAPHIC TOOL



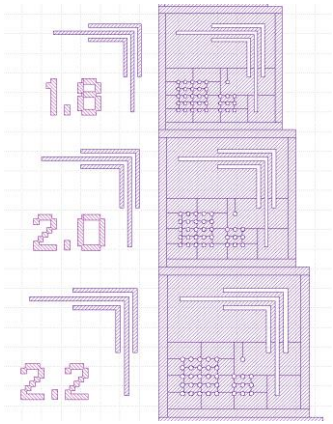
The prototype produces:

- Image size 2,5 x 2,5 mm
- Resolution 2 um
- 3D imaging

Image size and resolution were defined by the funding available. There are no physical limitations to produce higher resolutions or larger images.

4.3 LARGER IMAGE ON FLAT SURFACE

Original Topologies: elements with various resolution



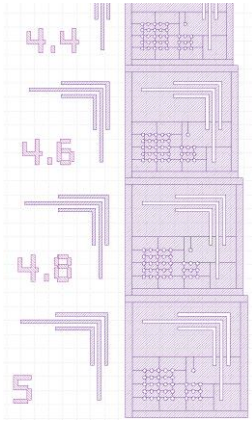


Image registered on CMOS camera

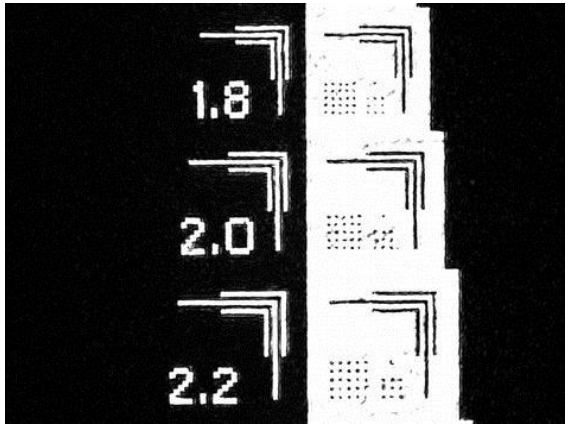
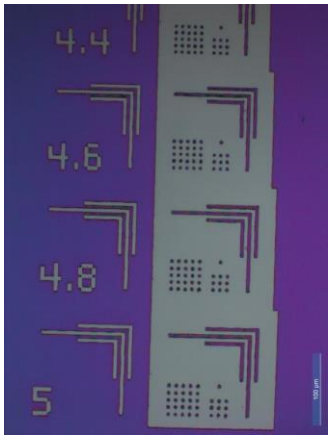


Image on photoresist

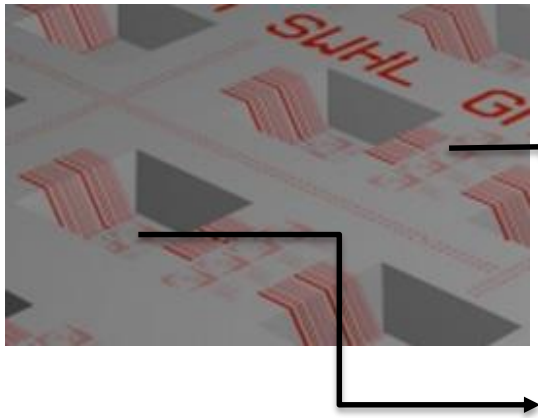


Results demonstrated that SWHL can produce larger images:

- Image size 2,5 x 2,5 mm
- Resolution 2 um

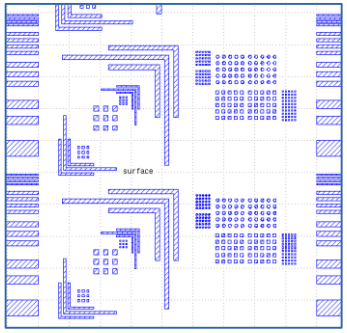
4.4 IMAGES ON MULTILEVEL SURFACE AT ONE EXPOSURE

Original design

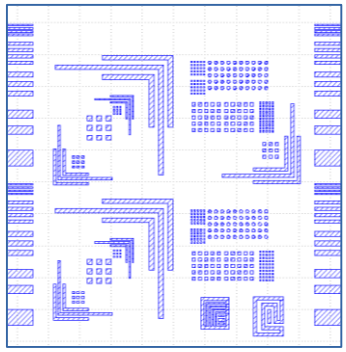


3D surface with topologies
on top and bottom surfaces.
Groove size 350 um x350 um.
Groove depth 100 um.

Original topology

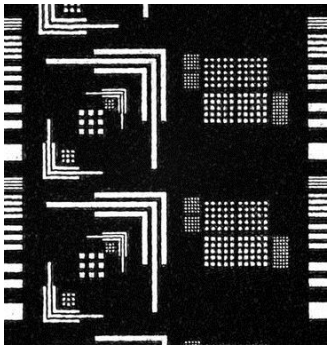


Top surface

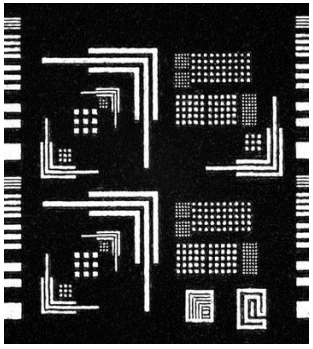


Bottom surface

Images produced on two surfaces with one mask at one exposure



Top surface

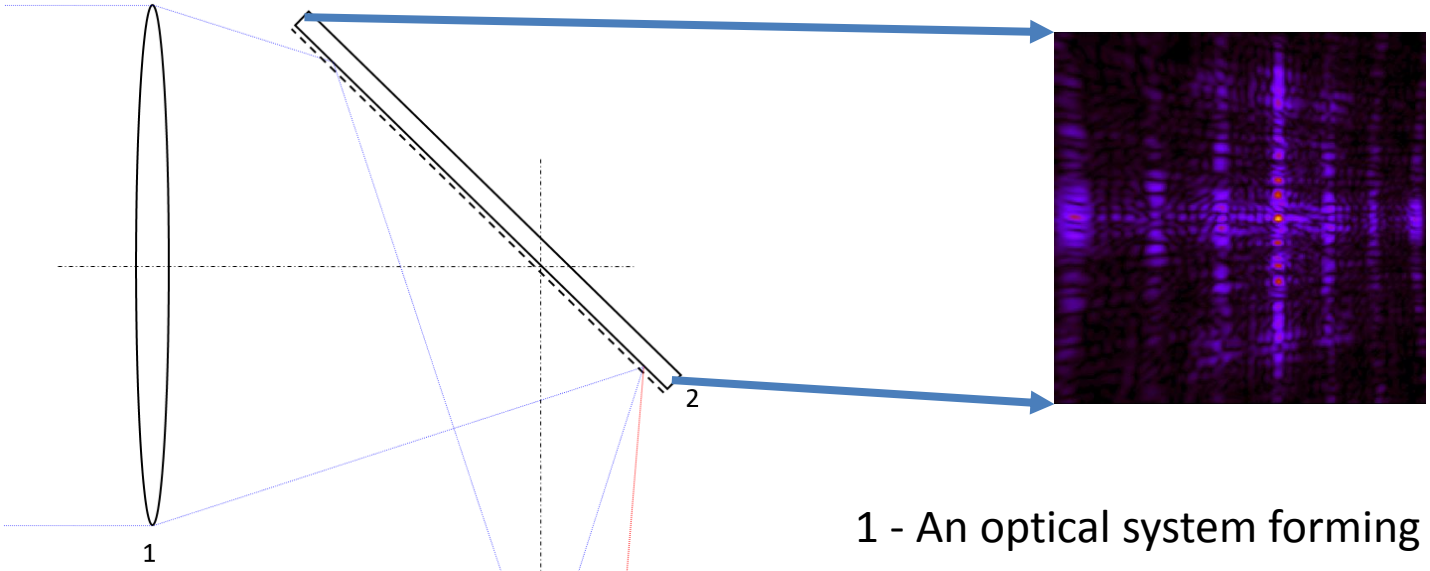


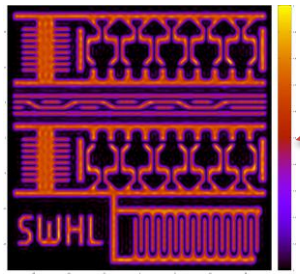
Bottom surface

Image size 2,5 x 2,5 mm
Resolution 2 um
Distance btw surfaces 100um
Images registered by
CMOS camera

Results demonstrated that SWHL can produce 3D images (images on multilevel surfaces located at distances much higher(≈100 times) then DoF) with one mask at one exposure.

Simple Optical Setup for Flat Reflective SLM



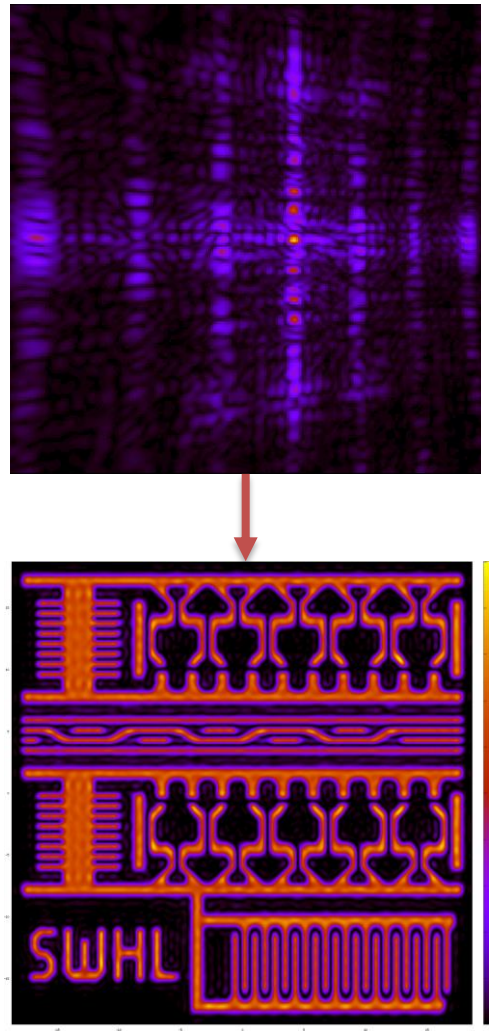


1 - An optical system forming a converging spherical wave;

2 - Flat controlled transparent (dynamic SLM);

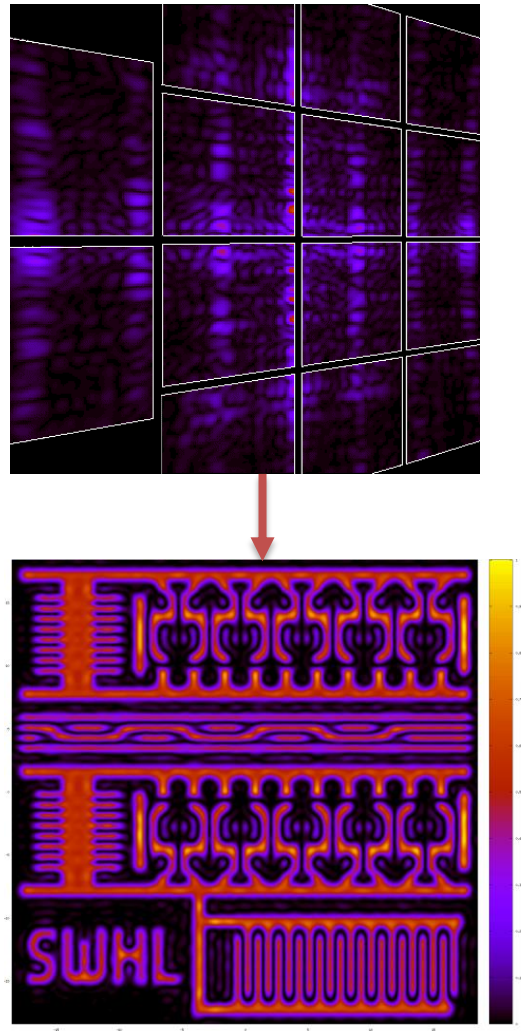
3 - The holographic image.

$NA_{max} \leq 0.6$

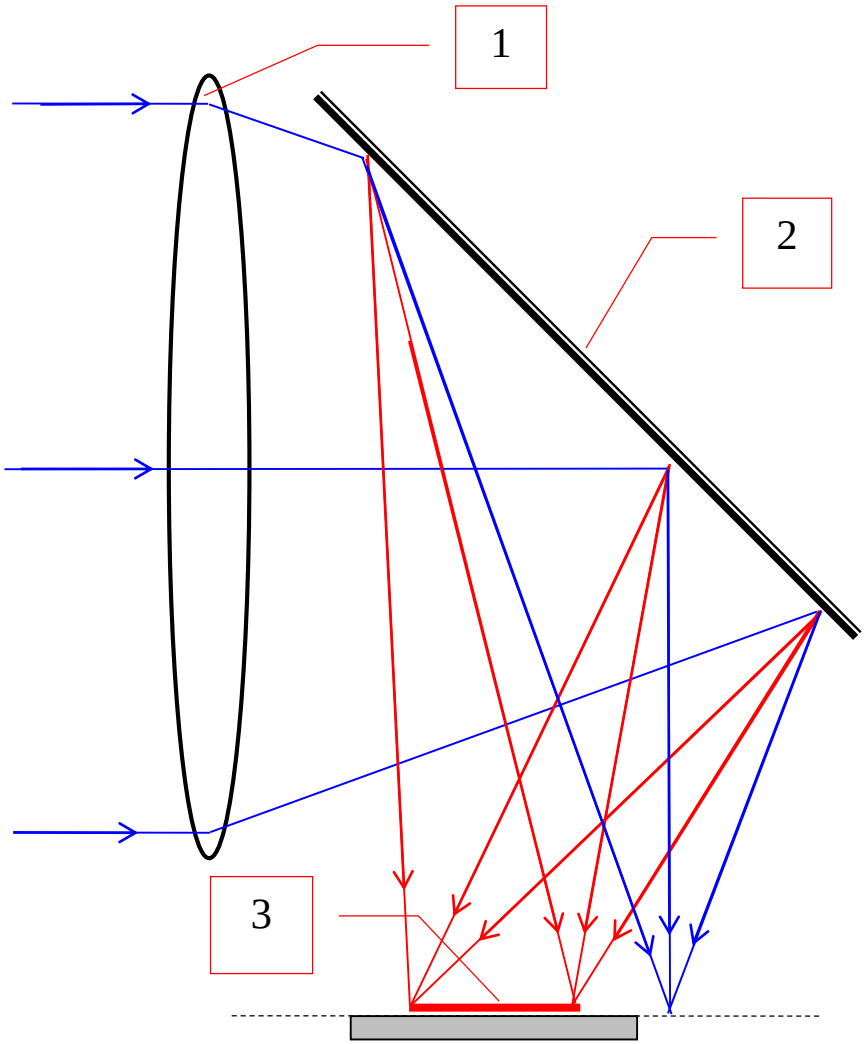


Frames -> Image Influence

Auxiliary elements of LCD, such as frames and connectors, will not appear on the image or destroy image quality, because of absence of one-to-one correspondence between mask and image elements and low sensitivity of holographic image quality to local mask defects.

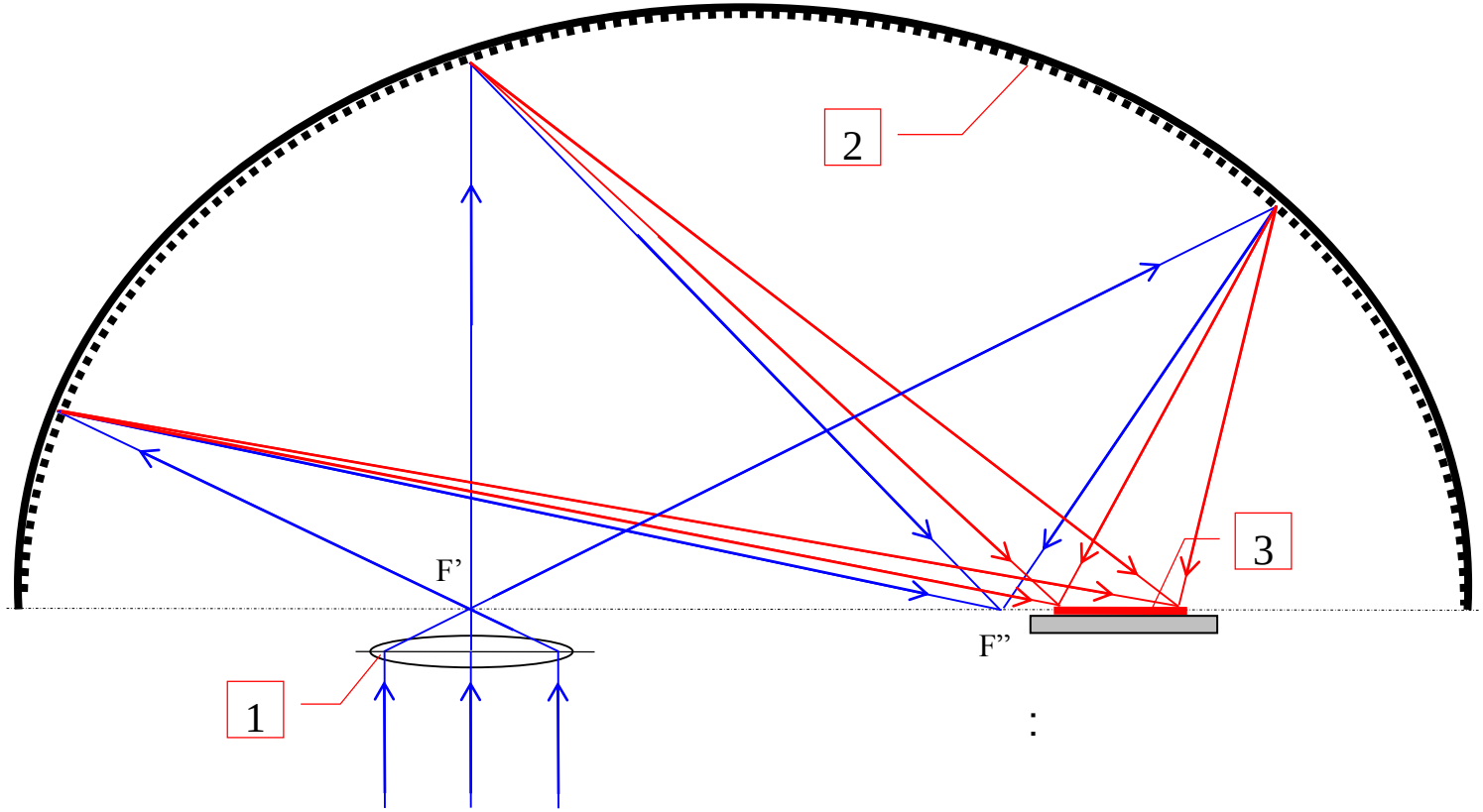


Optical scheme with flat mask



- 1 - Lens
- 2 – Flat mask
- 3 -Image on wafer
- NA ≤0.6
- Illuminator producing convergent wave

Optical scheme with ellipsoidal mask



:

:

1. Lens
2. Ellipsoidal mask
3. Image on wafer

NA ≤ 1

Illuminator producing divergent wave

Thank You for Attention!