Design, fabrication and characterization of diffractive optical elements

Coordinating prof.:

* Lect. PhD Ing. Liliana Preda

** Senior Scientist PhD Ing. Marian Zamfirescu

Student:

Ing. Călin Bogdan-Ștefăniță

* "Politehnica" University of Bucharest, Dept. of Physics

** National Institute for Laser, Plasma and Radiation Physics, Center for Advanced Laser Technologies

Presentation plan

- Purpose of this work
- CGH Design
- Fabrication methods
- Characterization
- Conclusions

Presentation plan

- Purpose of this work
- CGH Design
- Fabrication methods
- Characterization
- Conclusions

Purpose

- Study of computer generated holograms (CGH) and their binarization
- Development of at least one efficient method for digital hologram fabrication
  - Chosen "dummy" CGH: Airy beams
- Experiment with novel modulating functions

Presentation plan

- Purpose of this work
- CGH Design
- Fabrication methods
- Characterization
- Conclusions

Design

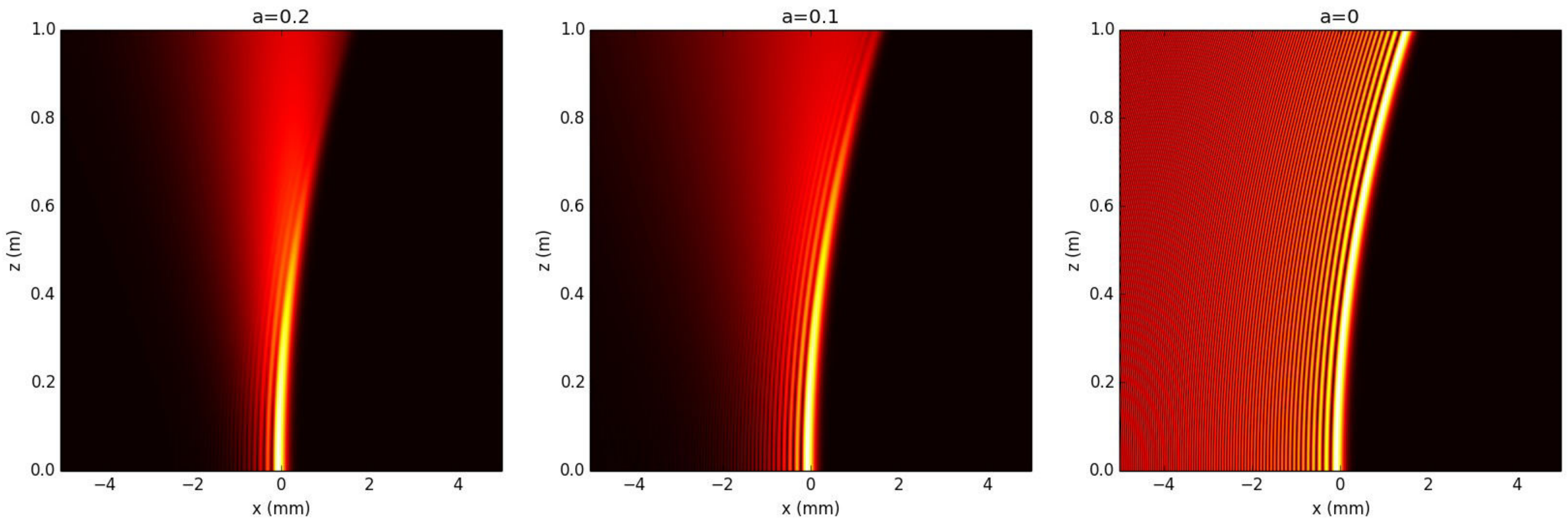
- From analytical solution:
  - Solution to Helmholtz equation → run simulation → calculate CGH
- Gerchberg-Saxton:
  - start from a random phase and minimize the errors
- Fraunhofer CGH:
  - simulate (sort of) the classical hologram fabrication method
- Binarization:
  - Most important part for fabrication
  - Not necessary, yet really helpful

From analytical solution: Airy beams

- Context regarding Airy beams
  - Berry and Balazs [1] - accelerating electron ***wave***packets
    - pure mathematics in the context of quantum mechanics, but then again: waves are waves -> no reason for light not to do that as well, therefore:
  - 2007, first experiment with optics (Siviloglou *et al* [2])
  - potential and features: ballistic propagation, nondiffraction, self-healing, etc

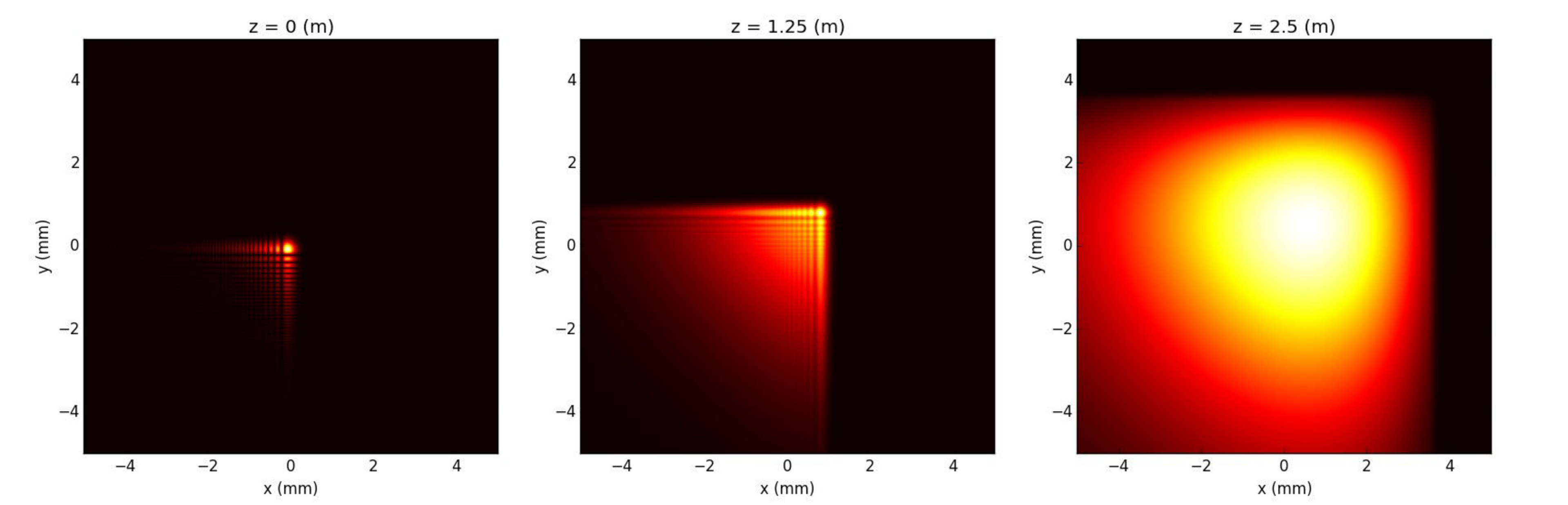
From analytical solution: simulations

- Airy beam longitudinal simulations:



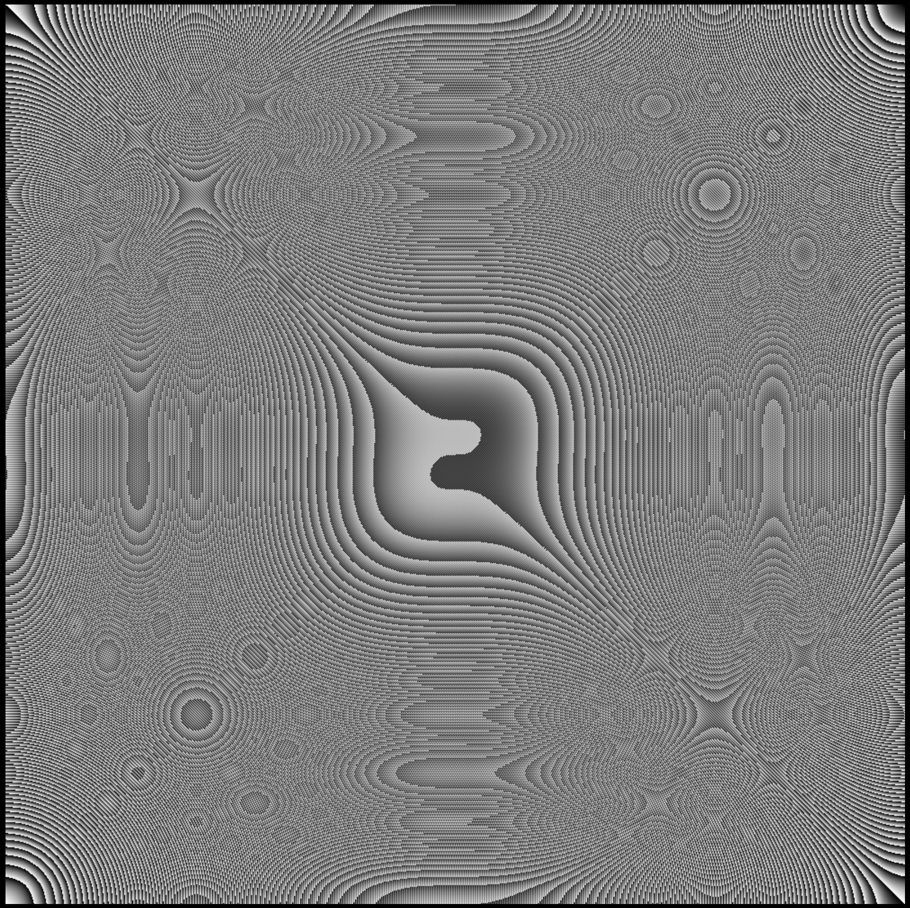
From analytical solution: simulations

- Airy beam transverse simulations for an attenuation constant a=0.05:

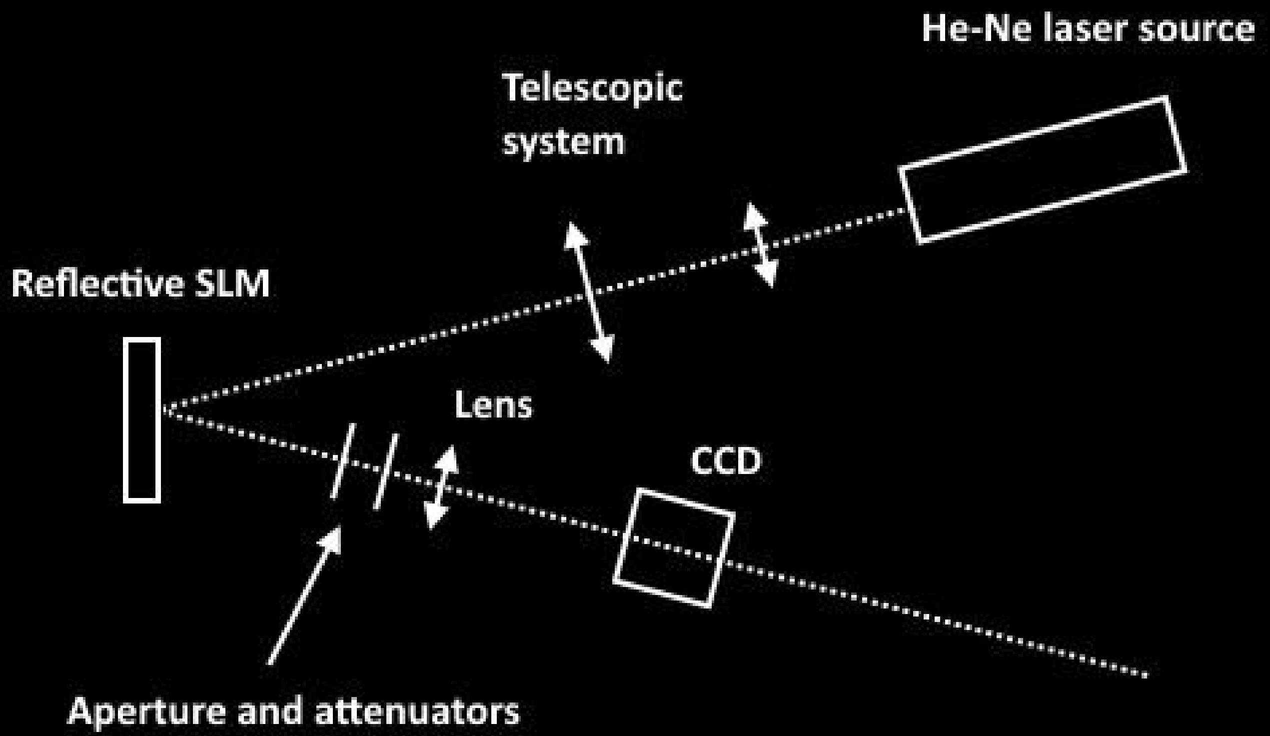


From analytical solution: the CGH

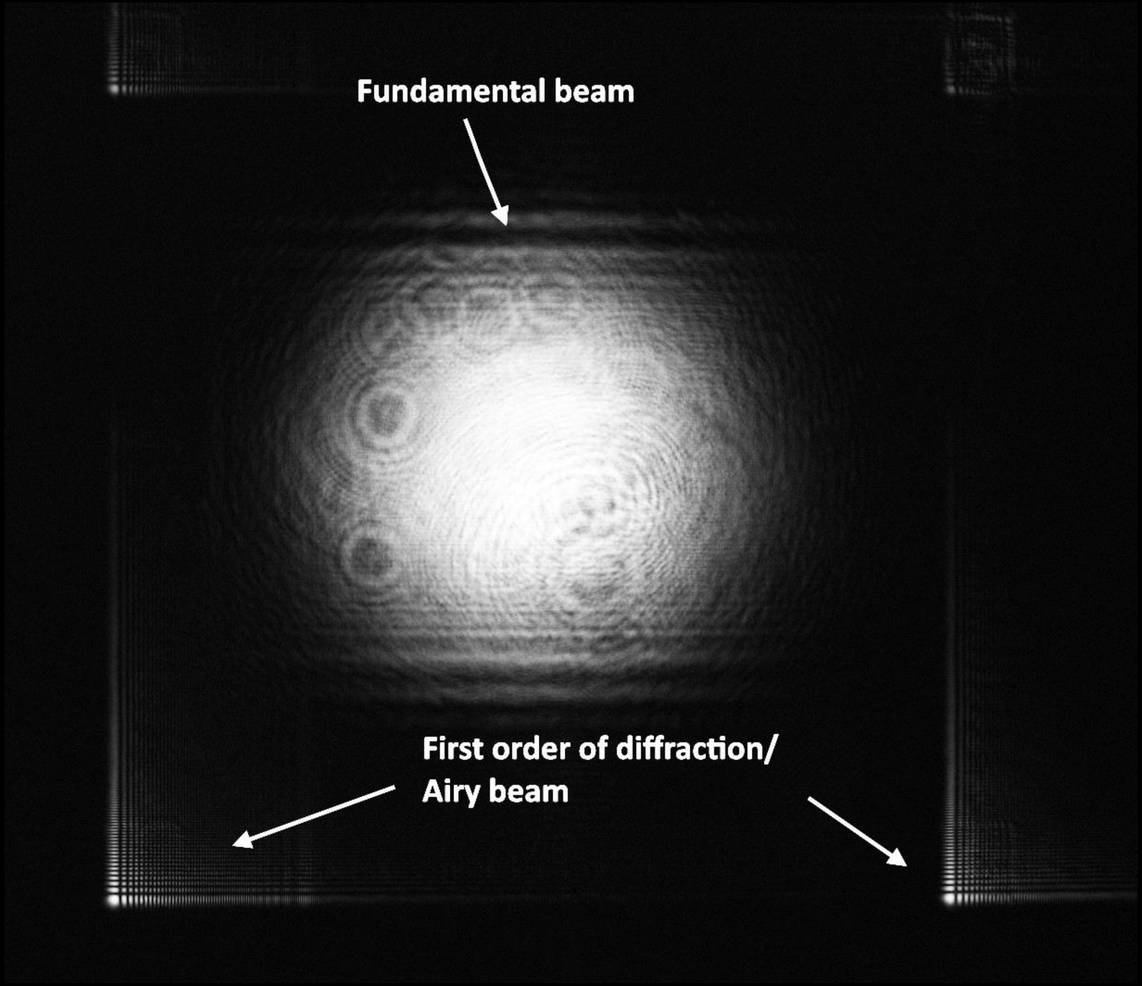
- Airy beam CGH (8-bit):



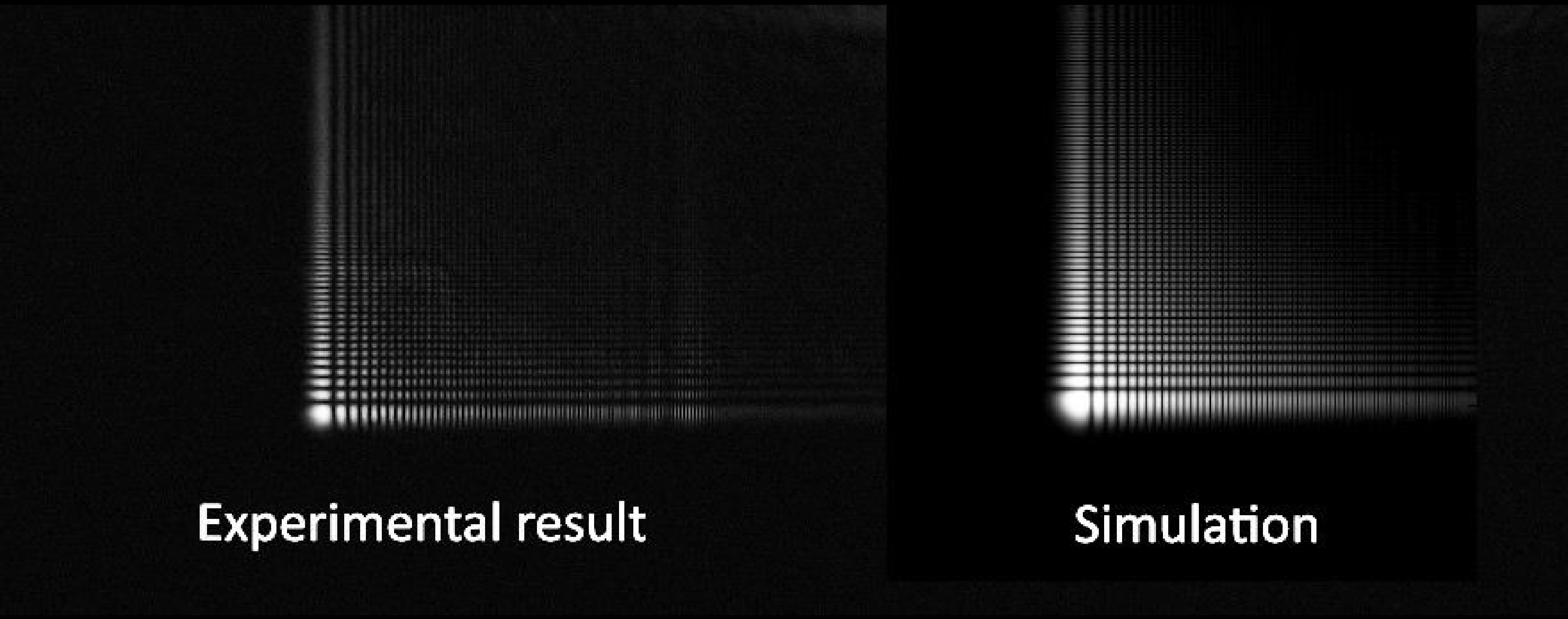
From analytical solution: does it work?



From analytical solution: results

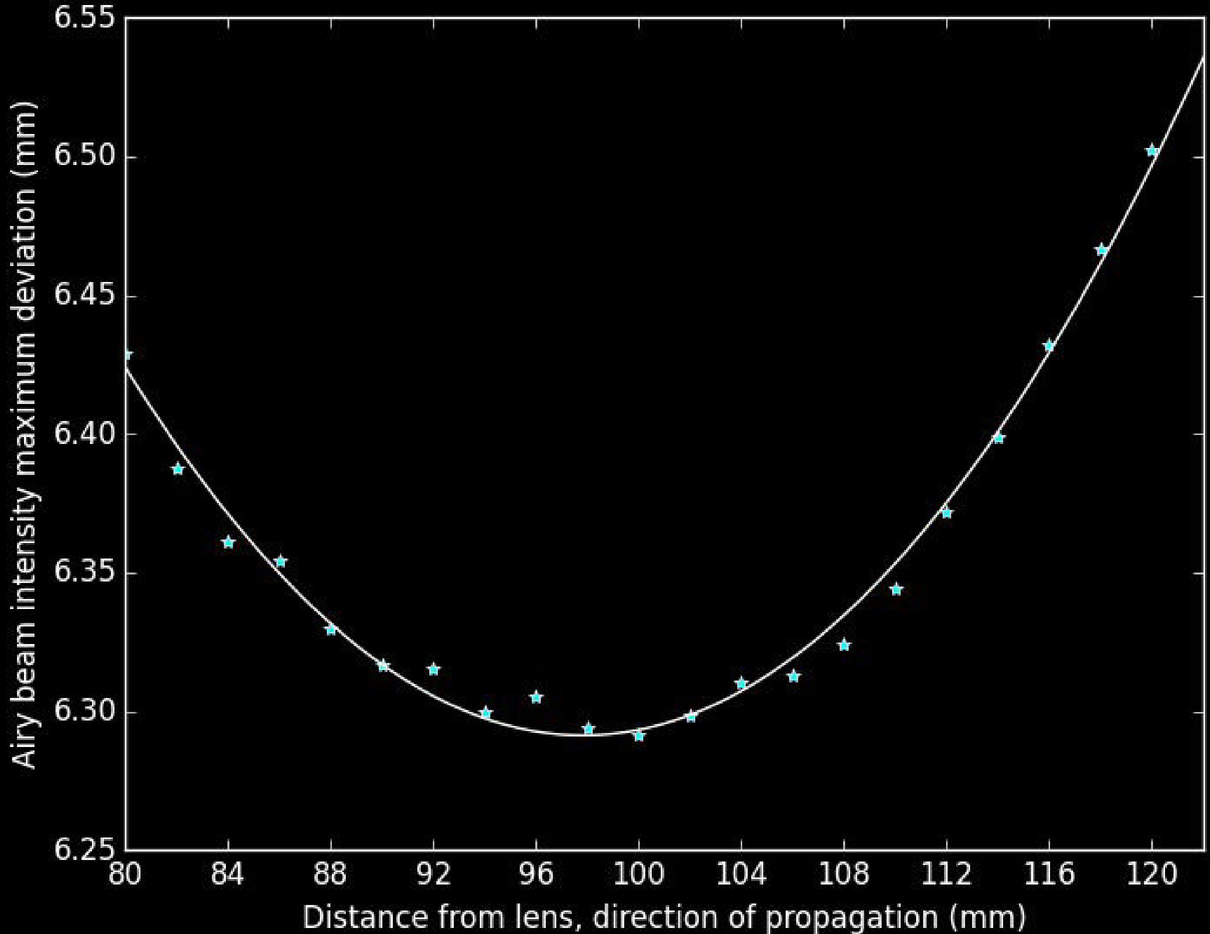


From analytical solution: comparison with the simulation



*! Where does the difference come from? The CCD's exposure.

From analytical solution: trajectory



Gerchberg-Saxton: original algorithm [3]

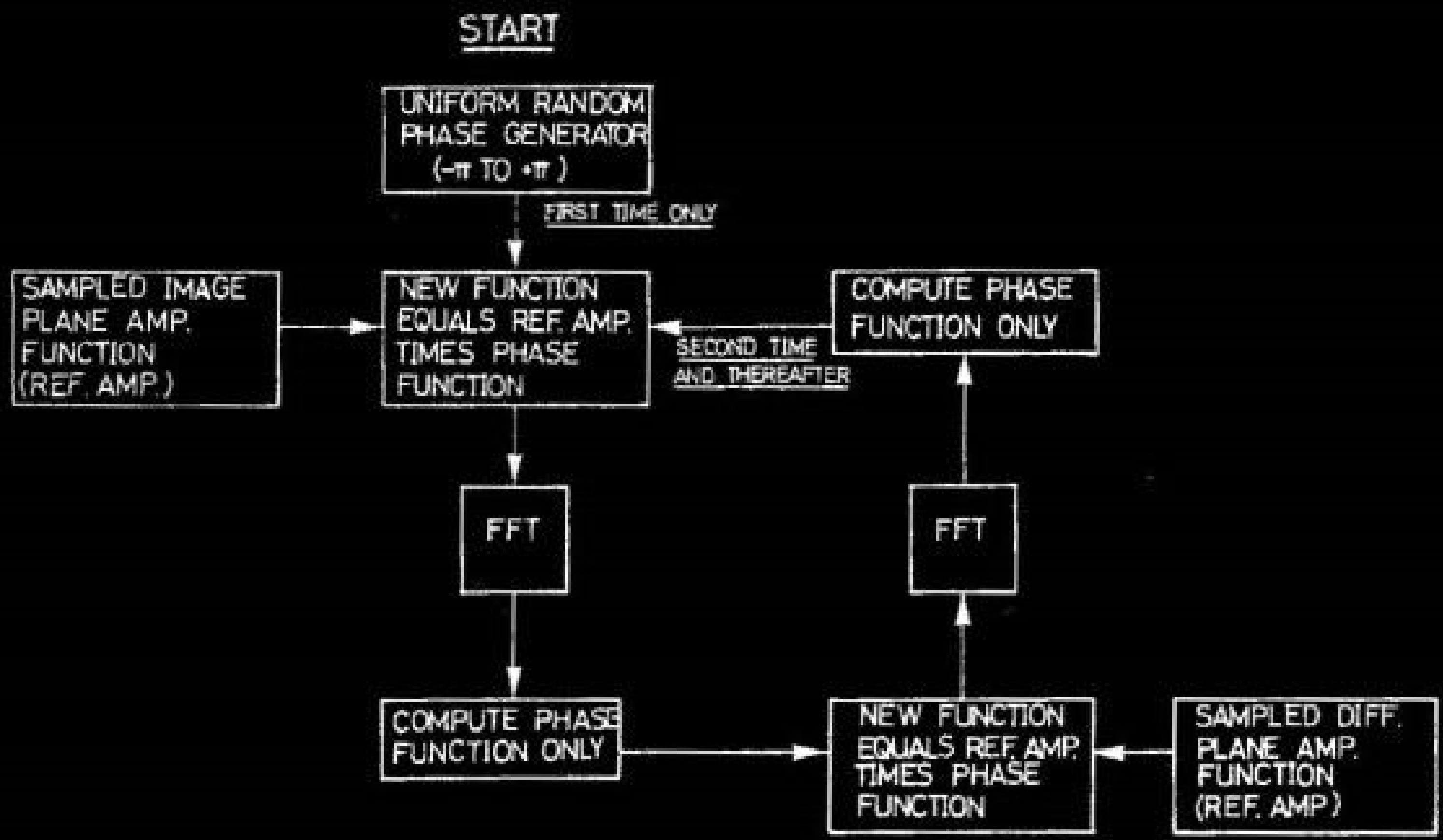
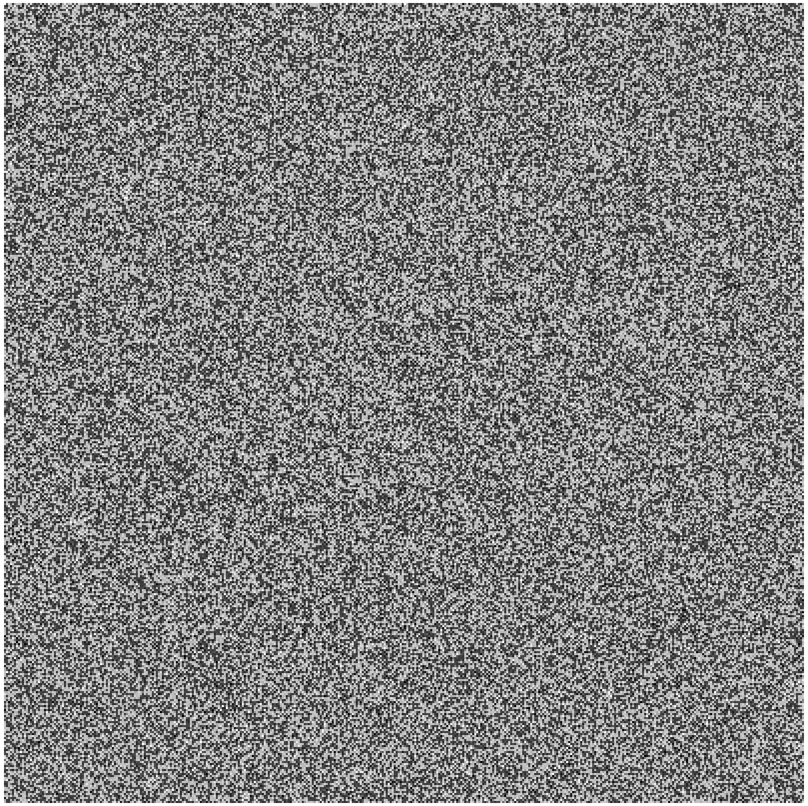


Fig. 1. Schematic drawing of phase determining algorithm.

Gerchberg-Saxton: input - CGH

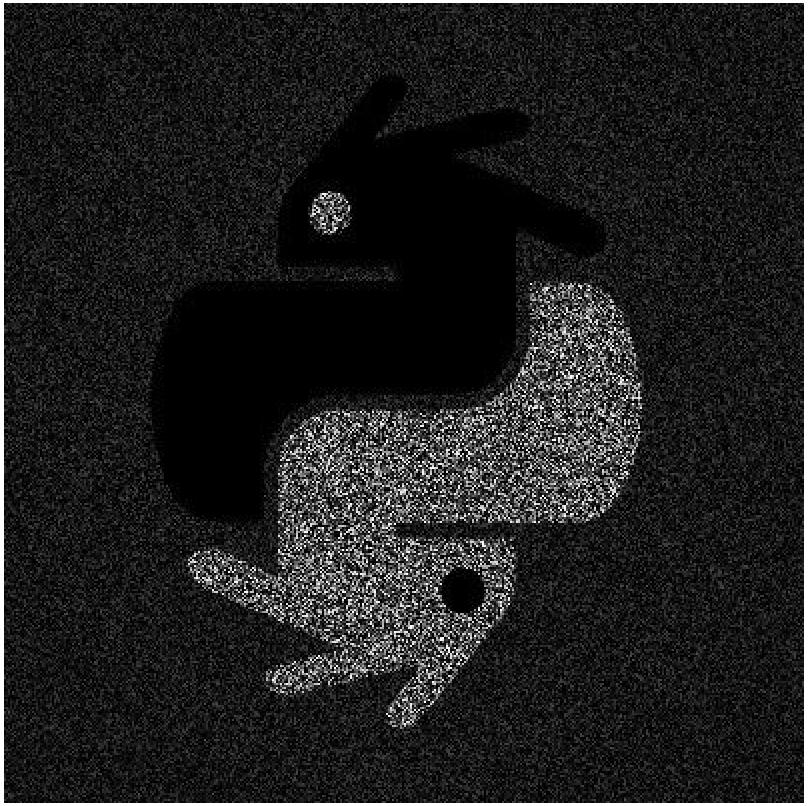
Input image

Resulted CGH (phase)

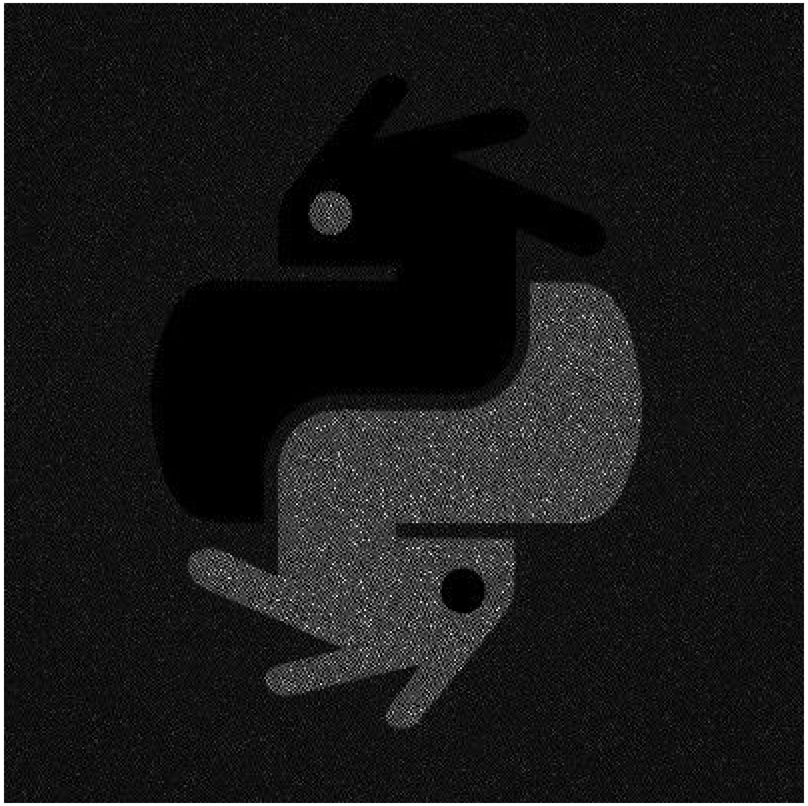


Gerchberg-Saxton: reconstructed image

1 iteration



10 iterations



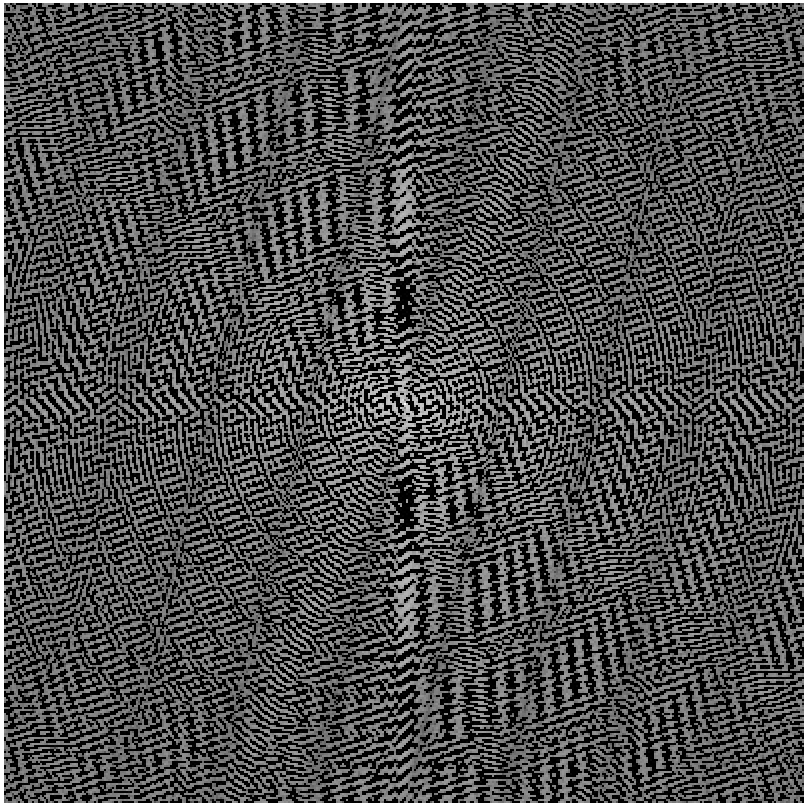
Fraunhofer CGH [4]:

- Create "object" and "reference" images*
  - Object == image we want to obtain
  - Reference == reference wave in classical holography
- FFT both, then add them (interference)
- Filter the result

Fraunhofer CGH: input - CGH

Input image

Resulted CGH (amplitude)



Fraunhofer CGH: input - reconstruction

Input image

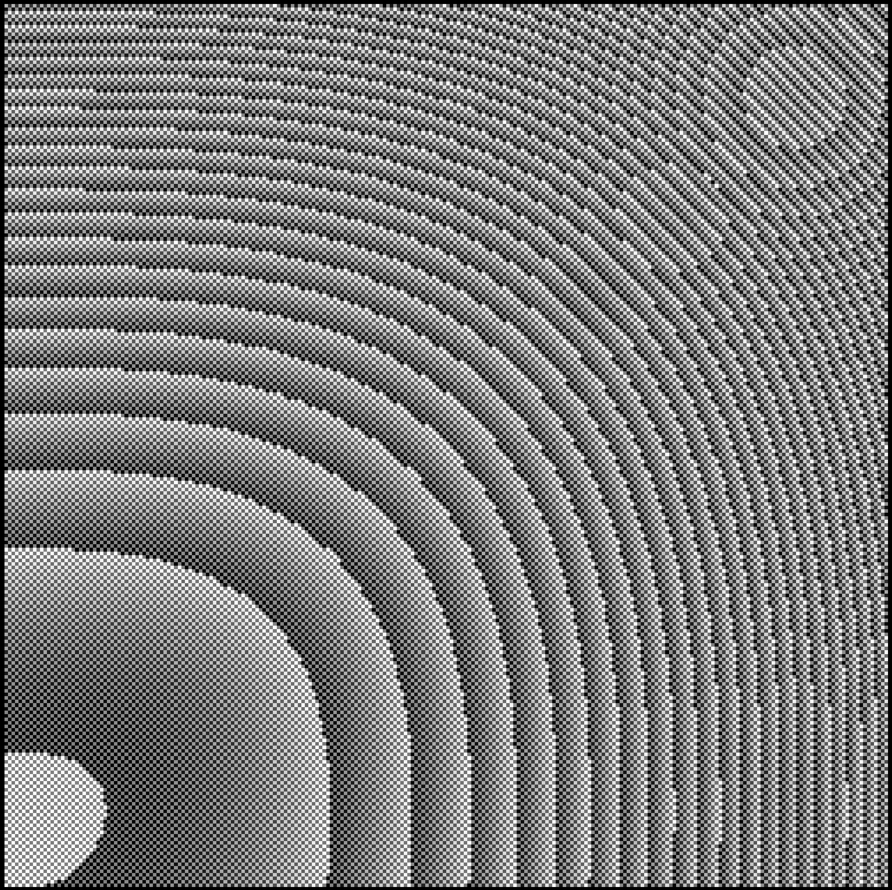
Reconstructed image

Binarization: why?

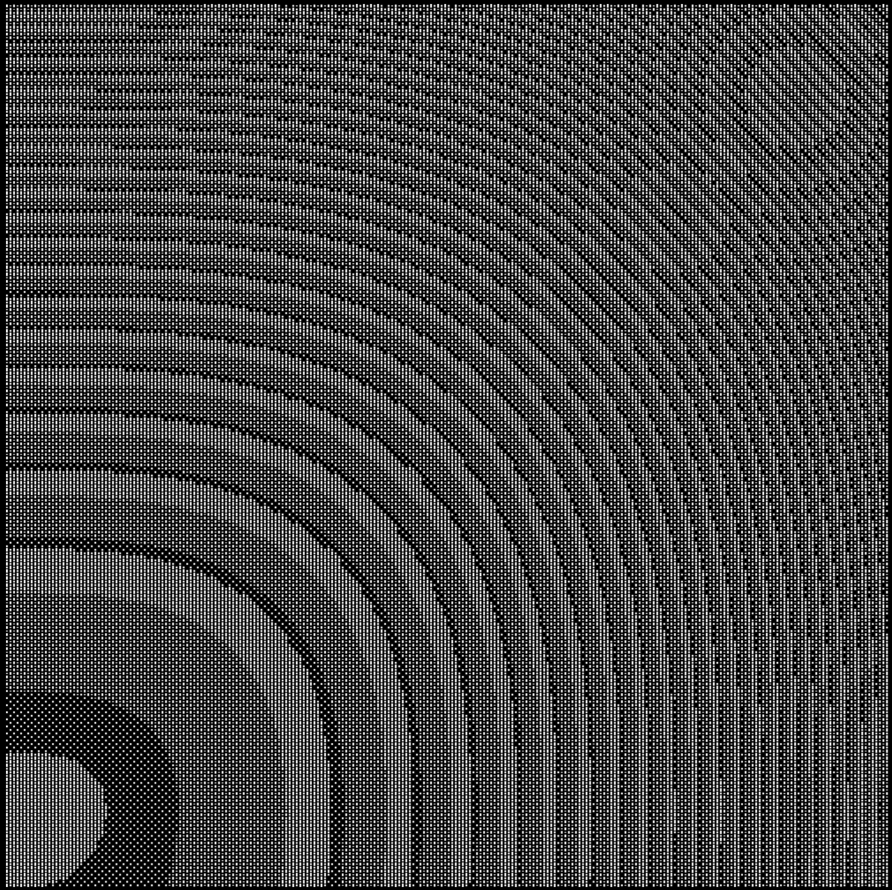
- CGH is a 256 gray levels (8-bit) bitmap
- Good results were obtained with 8 levels of gray (3-bit)
- Best case scenario: 2 levels, 0 and 1 / polymer and substrate / thin film and holes
- Solution: 1-bit CGH constructed as a 3-bit **equivalent**

Binarization: example

8-bit hologram

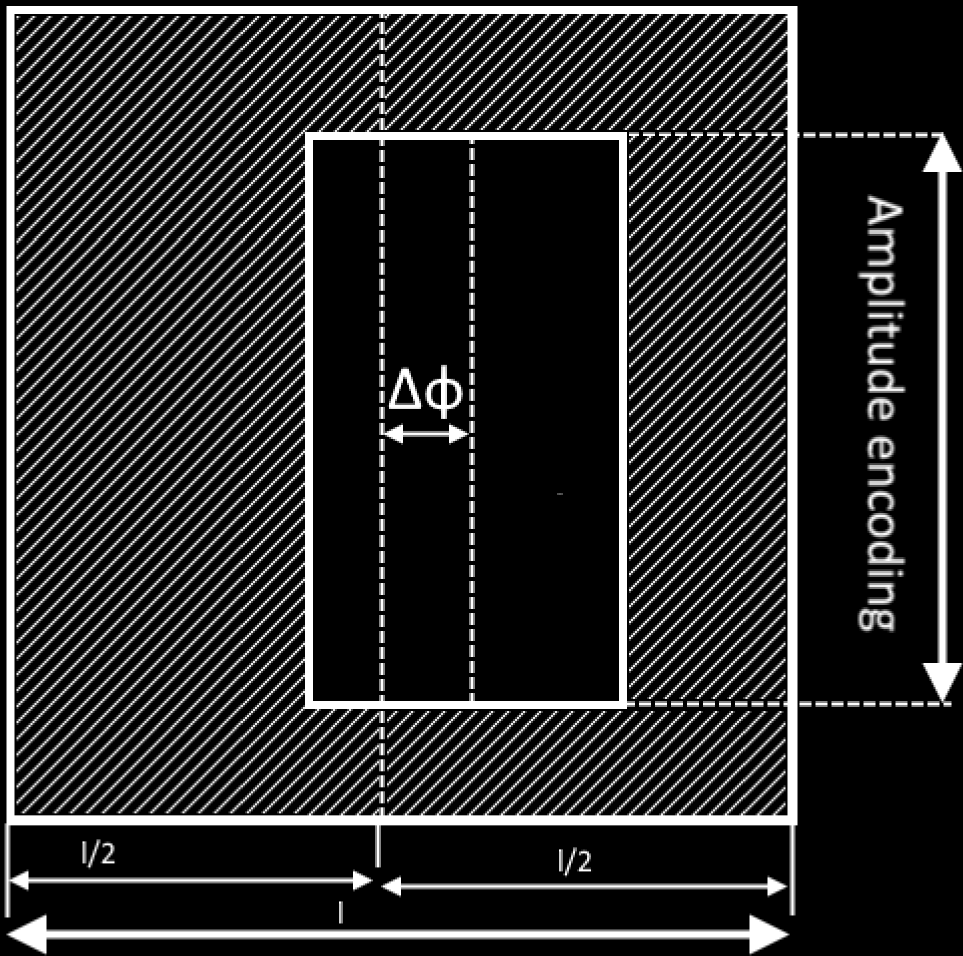


3-bit **equivalent** binary hologram

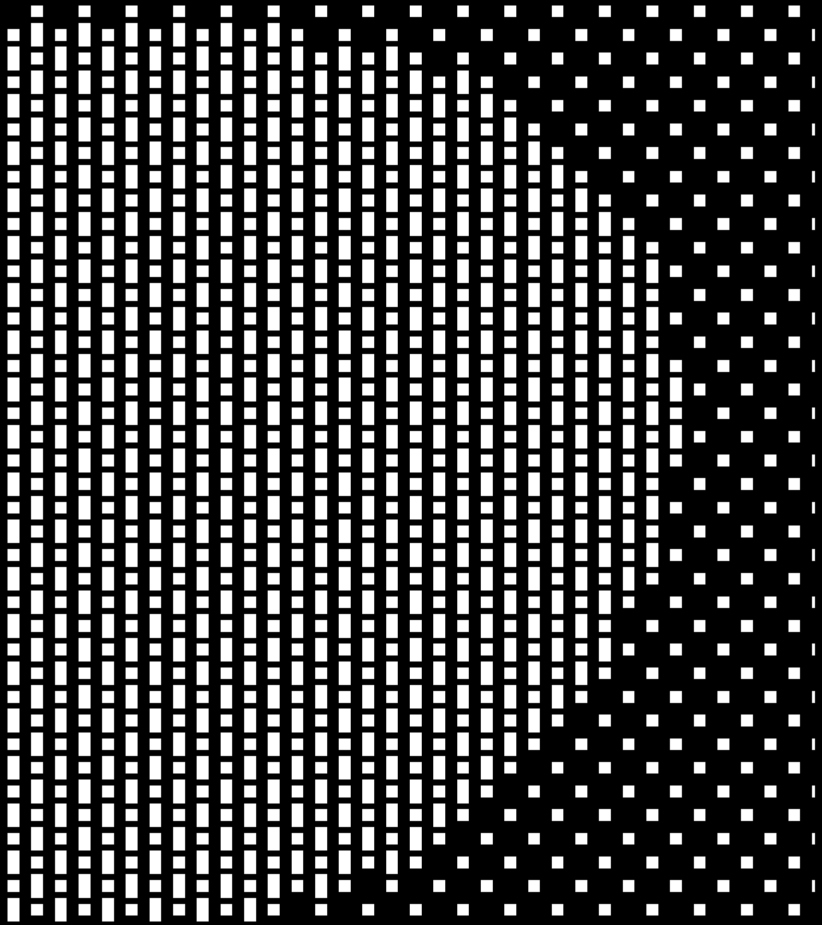


Binarization: how?

N-bit **equivalent** binary pixel



Zoom in of the 3-bit ***equivalent binary hologram***



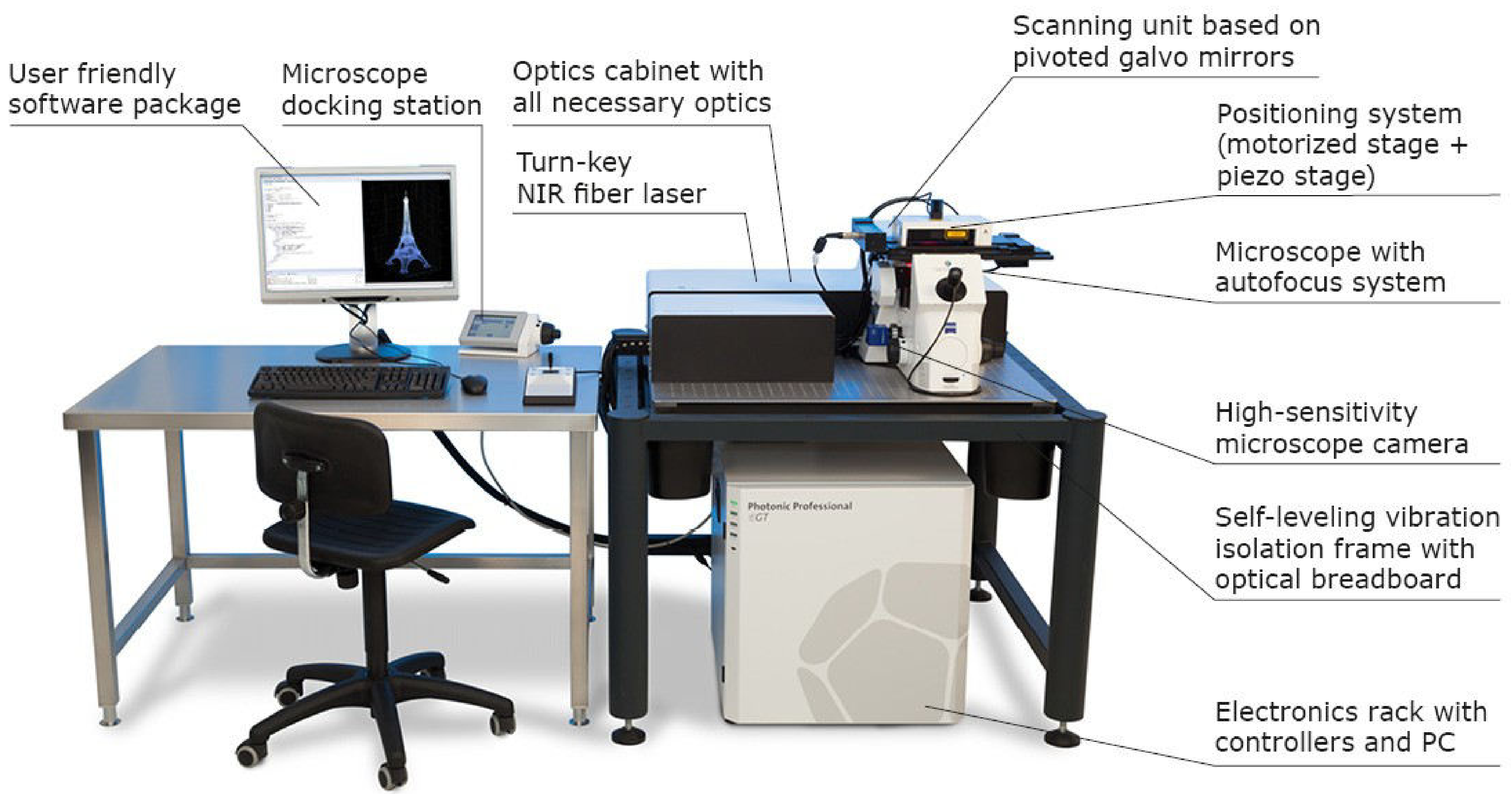
Presentation plan

- Purpose of this work
- CGH Design
- Fabrication methods
- Characterization
- Conclusions

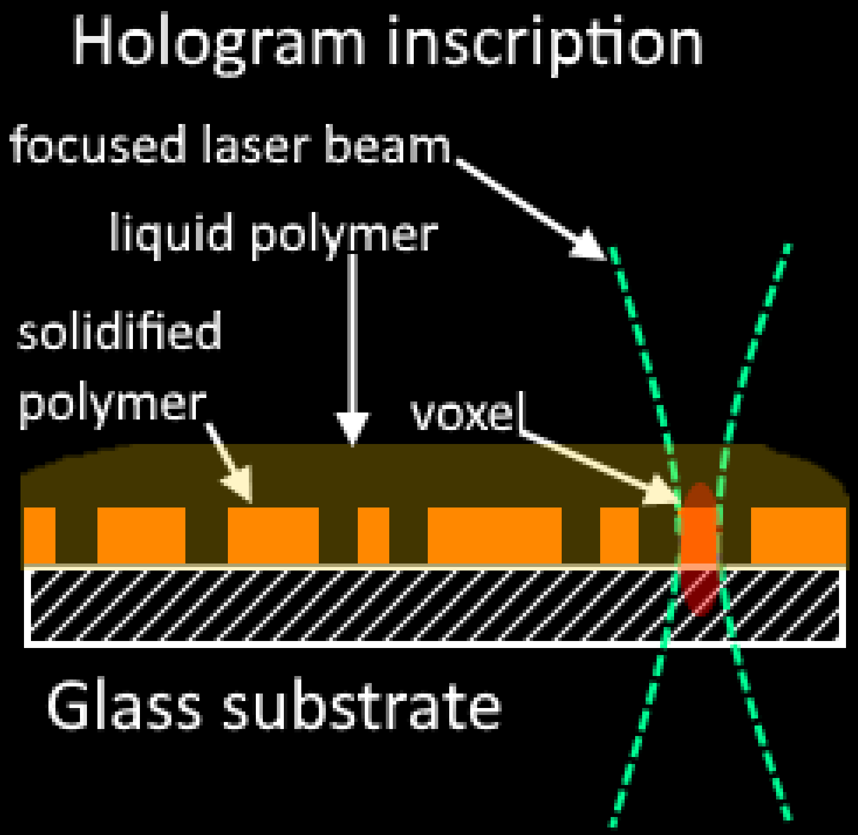
Fabrication methods

- Nanoscribe - *“3D printing on the micrometer scale”*
- Laser ablation – the straight forward solution

Fabrication methods - nanoscribe

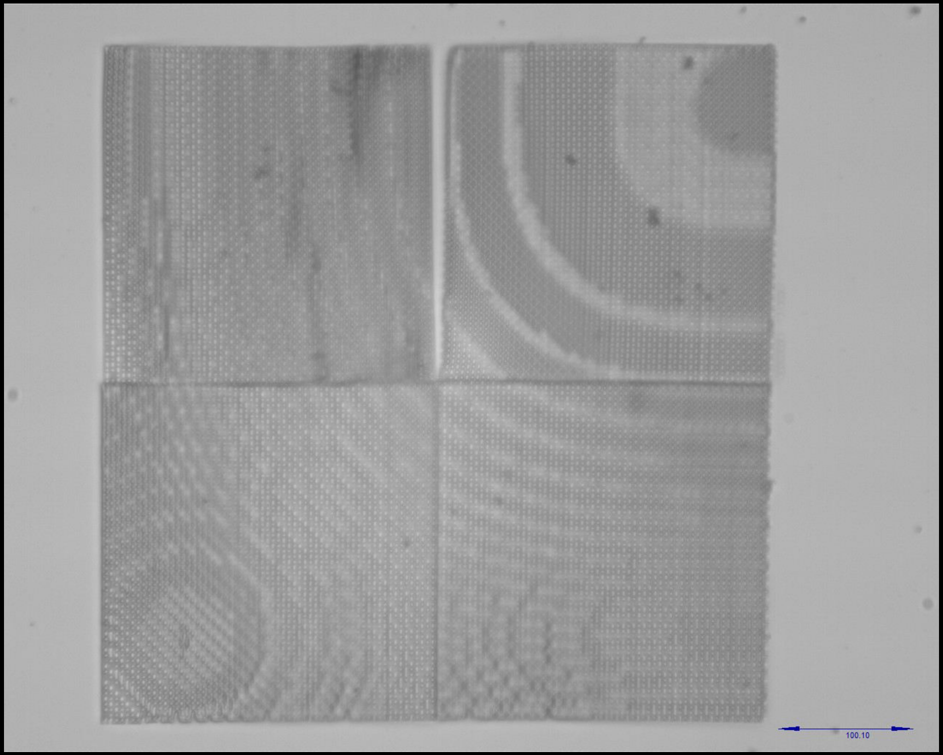


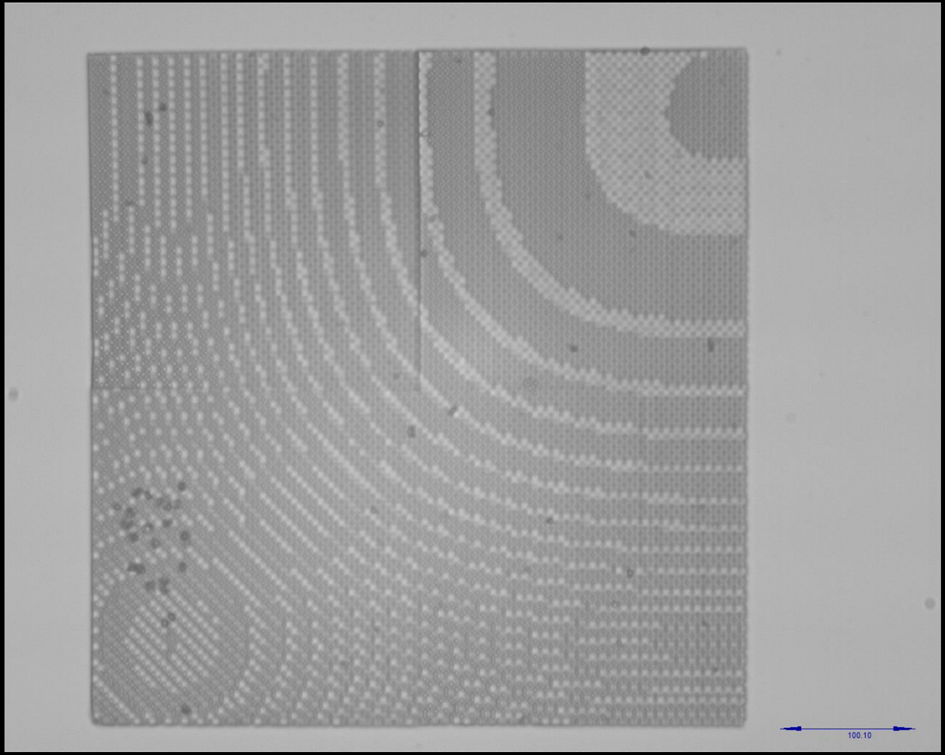
Nanoscribe: how does it work?



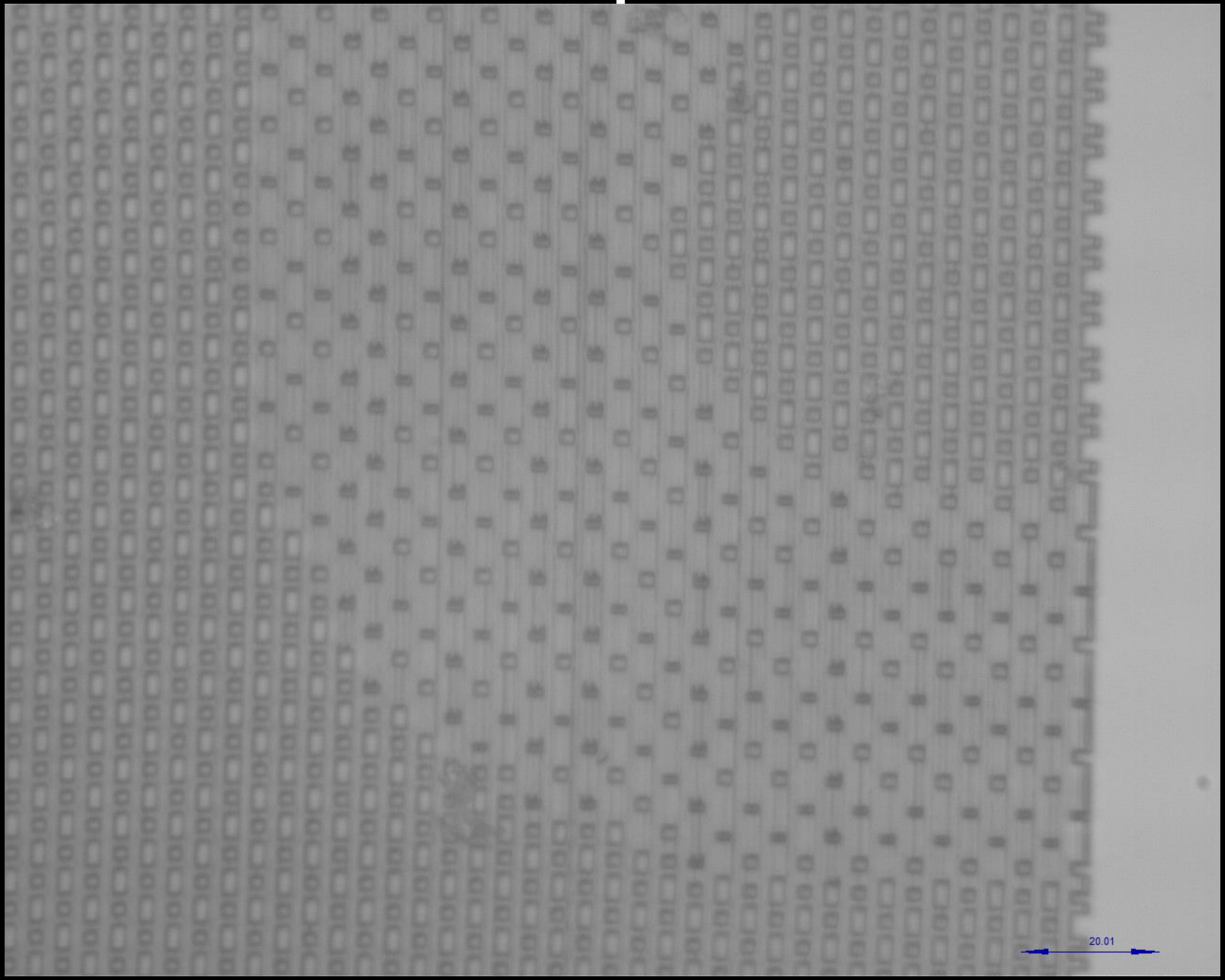
Nanoscribe: experimental results

~1 micron per pixel equivalent, 250 x 4 (encoded gray levels) pixels



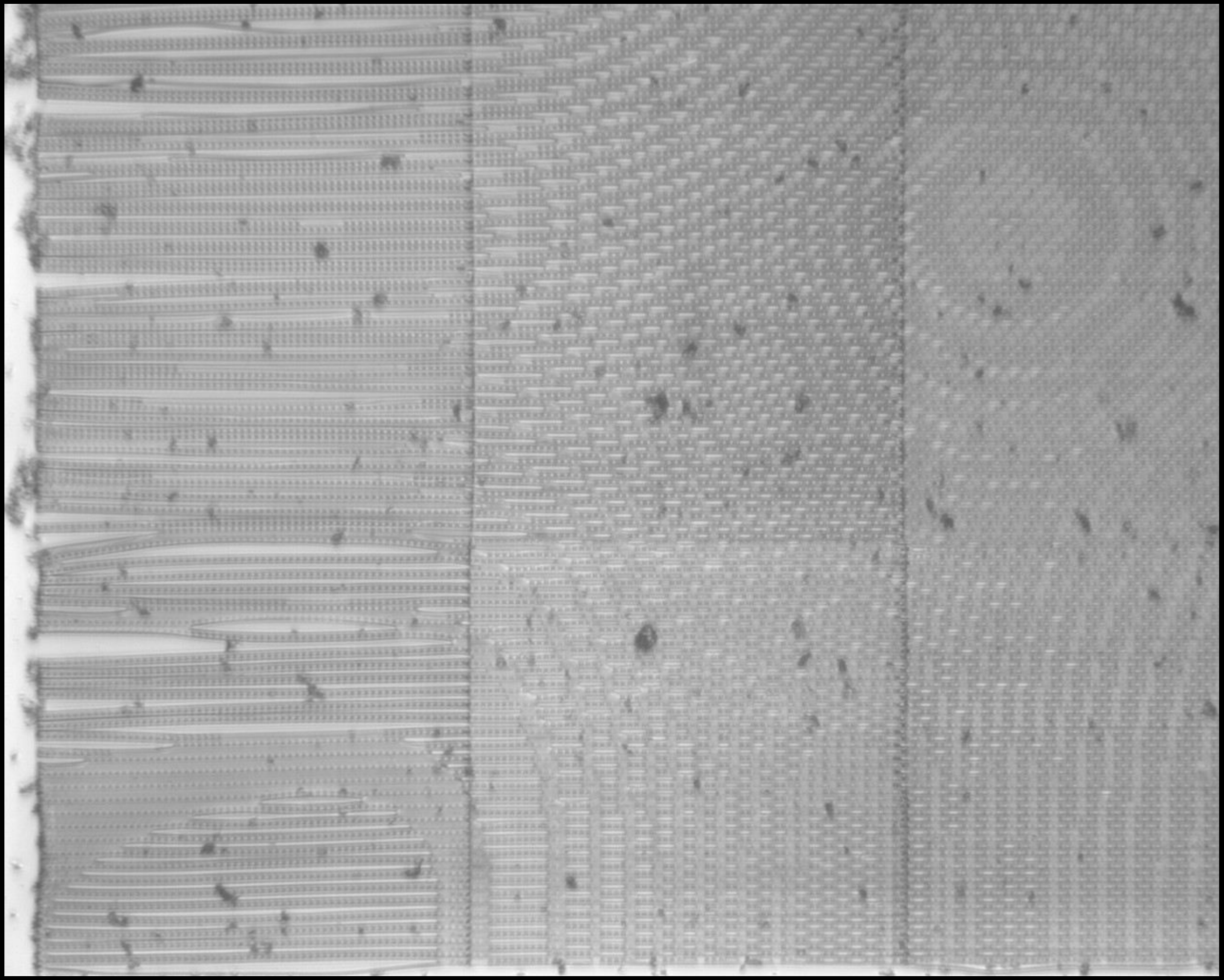


Nanoscribe: experimental results

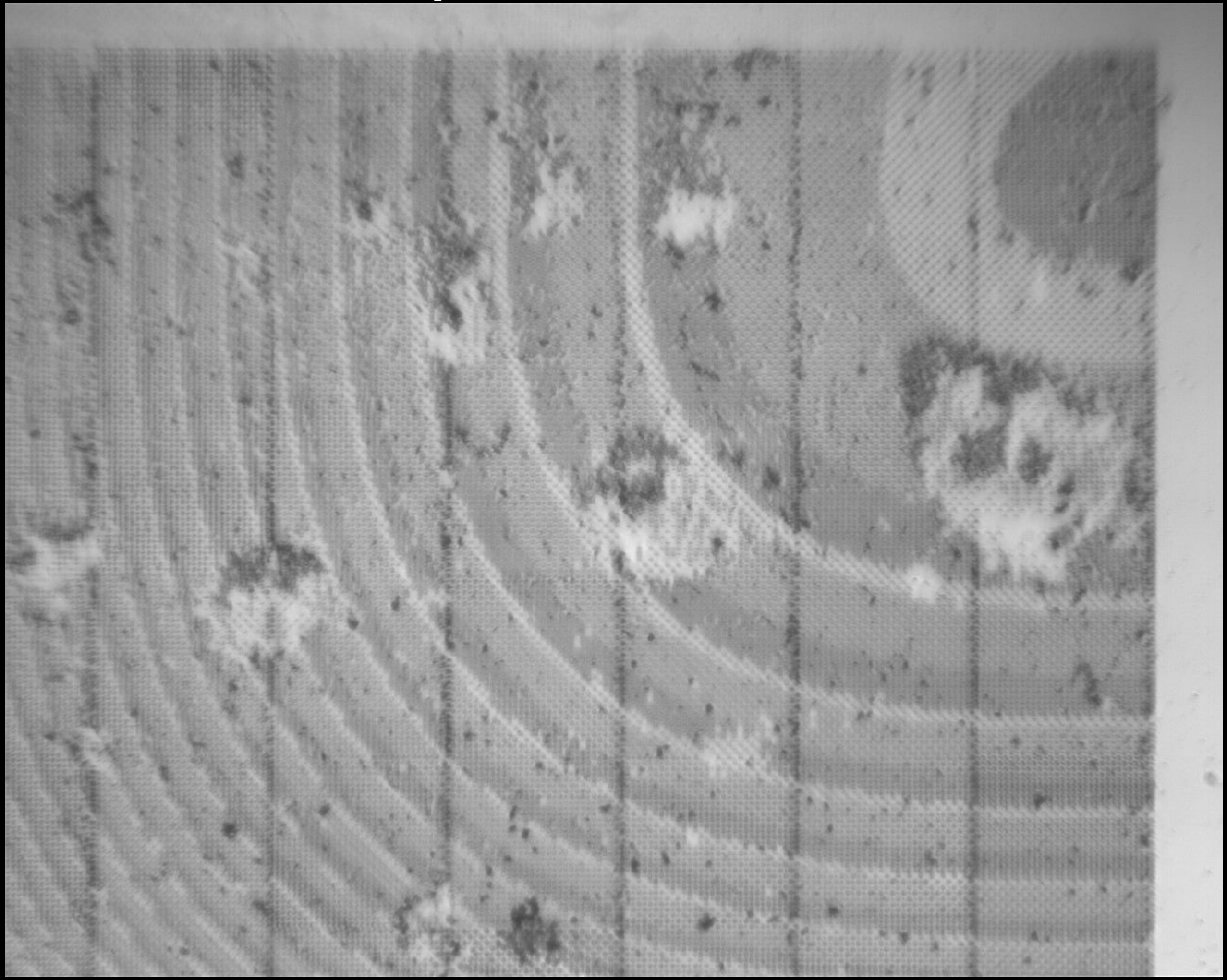


~1 micron per pixel equivalent

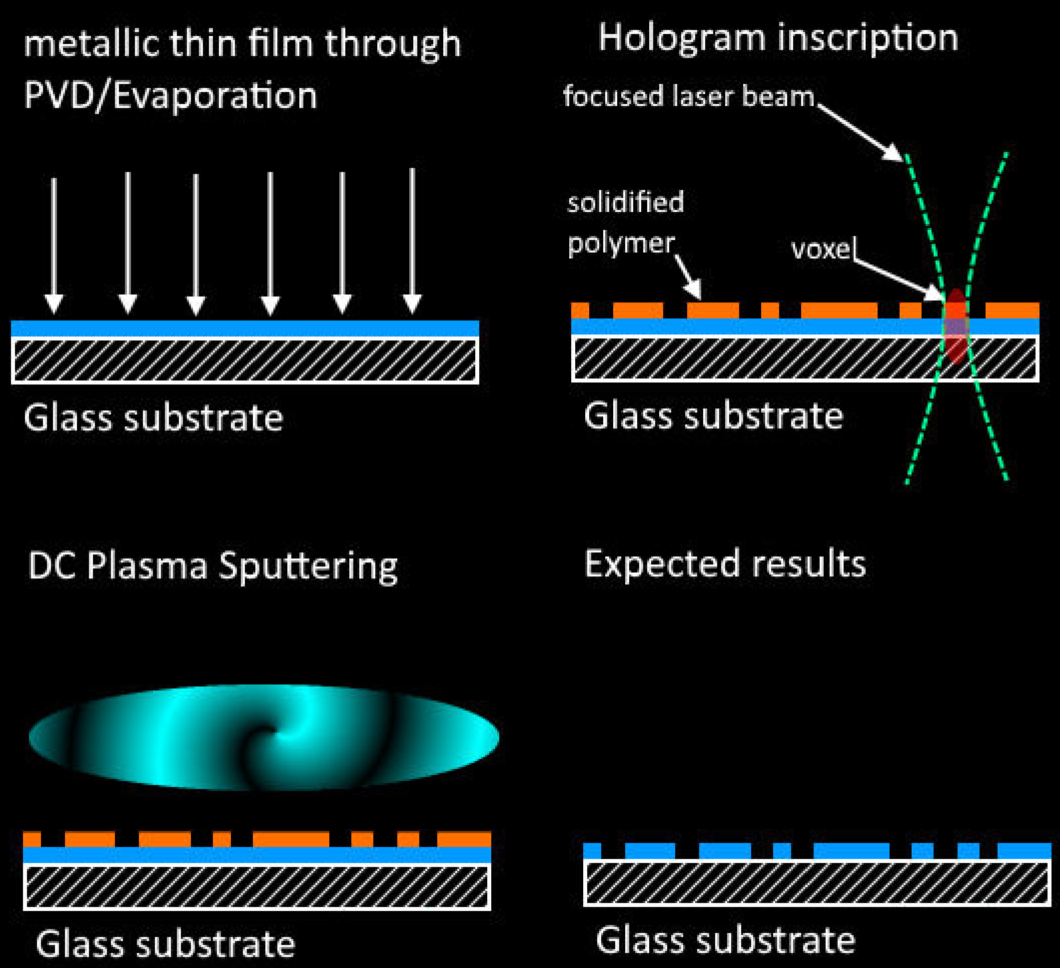
Nanoscribe: experimental results



Nanoscribe: experimental results

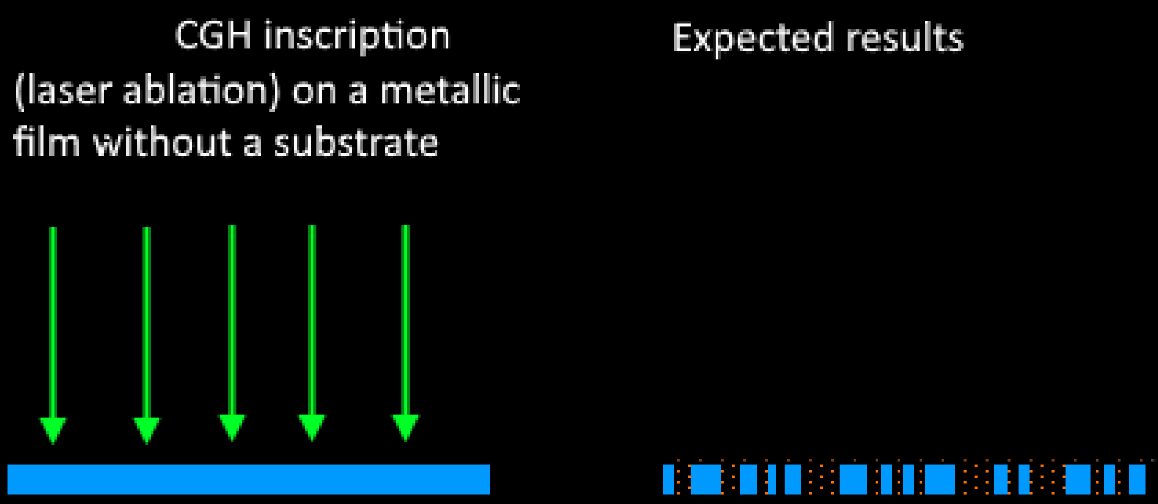


Nanoscribe: future developments



Laser ablation: principle

- Imprint the binary CGH in a thin (metallic) film



- Compared to nanoscribe: simpler, a little faster, but much lower pixel density

Presentation plan

- Purpose of this work
- CGH Design
- Fabrication methods
- Characterization
- Conclusions

Characterization

- Comparison of results between CGH and SLM
  - Image reproduction
  - Light efficiency
  - Noise
- Comparison of normal (256 levels) CGH and binary CGH (binary CGH have lower contrast)
- Structural characterization
  - % of “*misfired*” pixels
  - Homogeneity and structural integrity

Presentation plan

- Purpose of this work
- CGH Design
- Fabrication methods
- Characterization
- Conclusions

Conclusions

- Developed an integrated software package for CGH calculation (GUI in progress)
  - Airy beams
  - Arbitrary images with GS or Fraunhofer numerical methods
  - Binarization
- Constructed CGH with the nanoscribe installation
  - Method can still be improved
- Currently building the other (laser ablation) CGH fabrication installation

Thank you for your attention!

References

[1] M. V. Berry, N. L. Balasz, "Nonspreading wave packets", Am. J. Phys, vol. 47, nr. 3, pg. 264-267, 1979;

[2] G. A. Siviloglou, D. N. Christodoulides, "Accelerating finite energy Airy beams", Opt. Let. vol. 32, nr. 8, pg. 979-981, 2007;

[3] R. W. Gerchberg and W. O. Saxton, "A Practical Algorithm for the Determination of Phase from Image and Diffraction Plane Pictures", Optik, vol. 35, no. 2, pp. 237-246, 1972

[4] Divya P. S. et al, "A study and simulation of Computer Generated Holograms", IJAET, vol. 6, no. 3, pp. 1340-1347, 2013

[4] G. A. Siviloglou, "Accelerating optical Airy beams", University of Central Florida, Orlando – Florida, 2010;

[5] Jill E. Morris, "Studies of novel beam shapes and applications to optical manipulation", University of St. Andrews - Scotland, 2010;

[6] Peng Zhang et al., "Nonparaxial Mathieu and Weber Accelerating Beams", Phys. Rev. Let. 109, 193901, 2012;