Abbe Center of Photonics | JENA
Friedrich-Schiller-Universität

Photonische Nanomaterialien

Polarisationskontrolle und hochdispersive computergenerierte Hologramme

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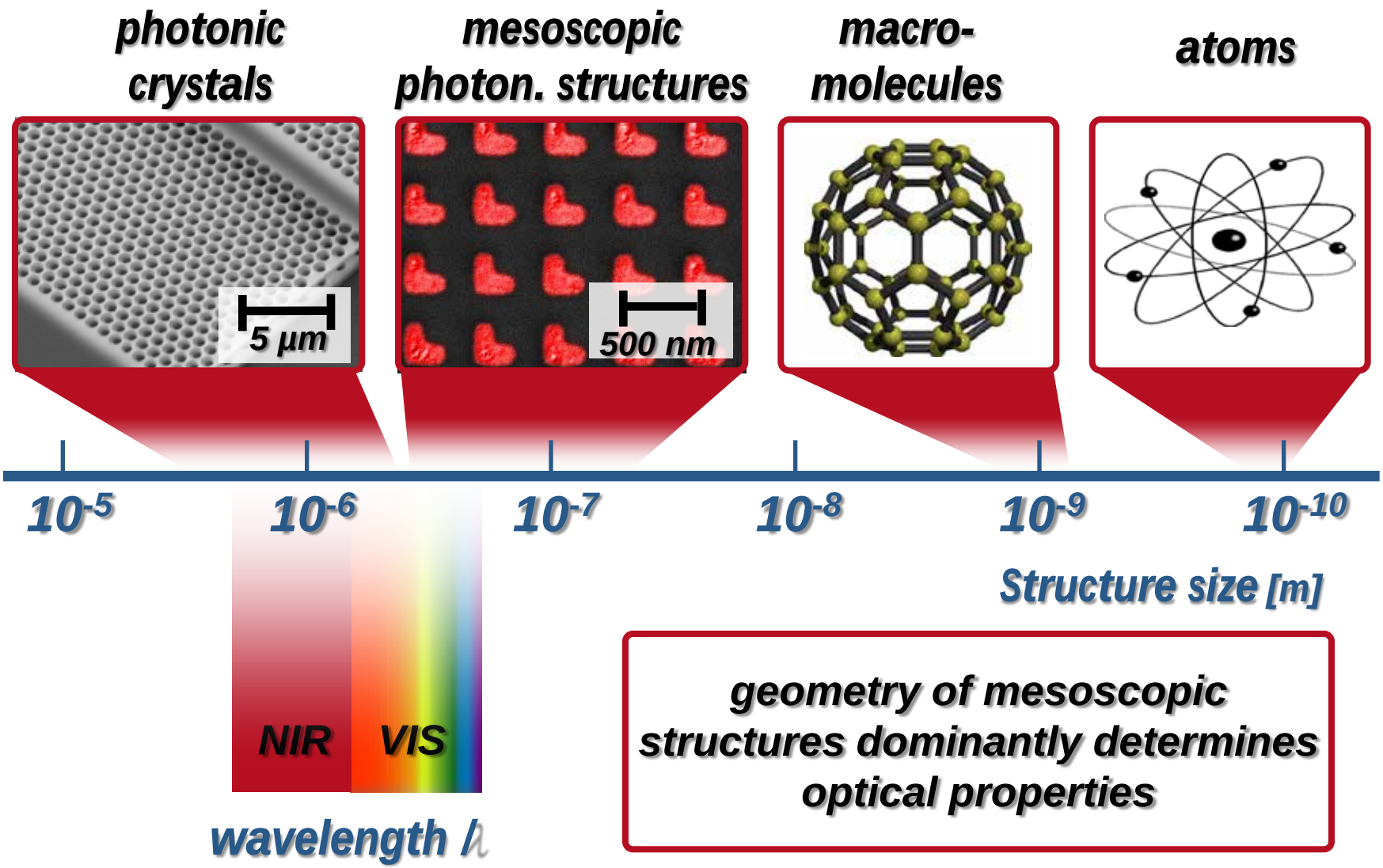
Bundesministerium für Bildung und Forschung

Mesoscopic photonic struktures



geometry of mesoscopic structures dominantly determines optical properties

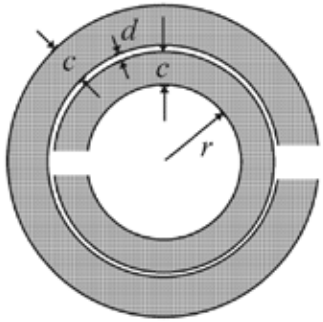
Short history of metamaterial research

theory n<0

Veselago, Sov. Phys. Usp. **10**, 509 (1068).

1968

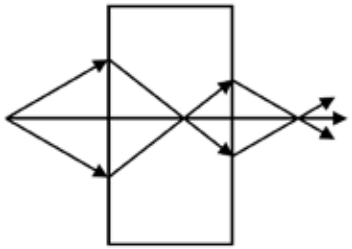
artificial magnetism



Pendry et al., IEEE Trans. Microw. Techn. **47**, 2075 (1999).

1999

perfect lens with n<0



Pendry, Phys. Rev. Lett. **85**, 3966 (2000).

2000

2001

scaling of technologies to nanoscopic structures

Short history of metamaterial research

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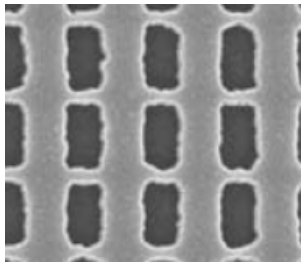
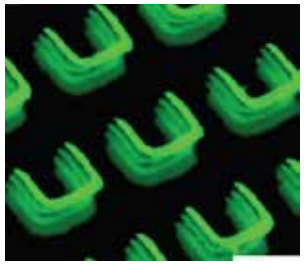
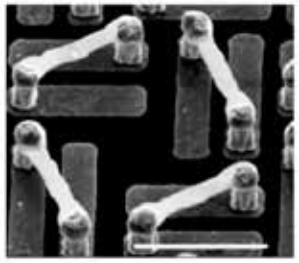
complex metaatoms



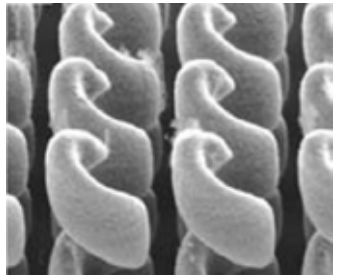
Dolling et al., Opt. Lett. ***31****, 1800 (2006)*



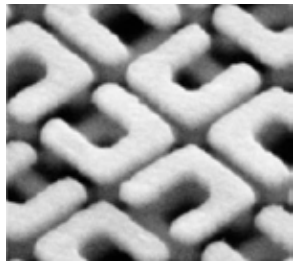
Liu et al., Nat. Mater. ***7****, 31 (2008)*



Zhang et al., Phys. Rev. Lett. ***102****, 023901 (2009)*



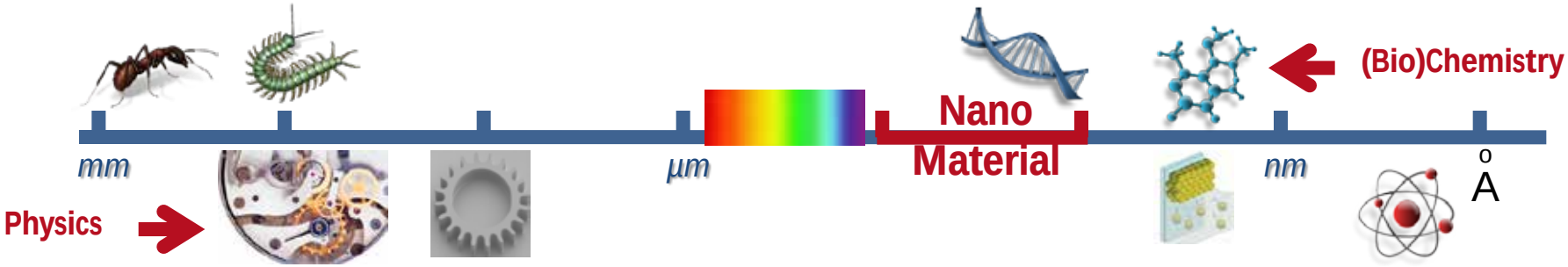
Gansel et al., Science ***325****, 1513 (2009)*

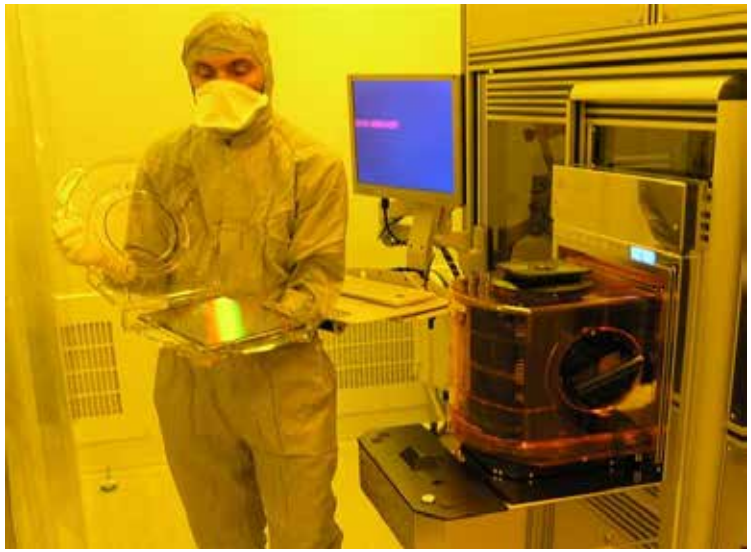


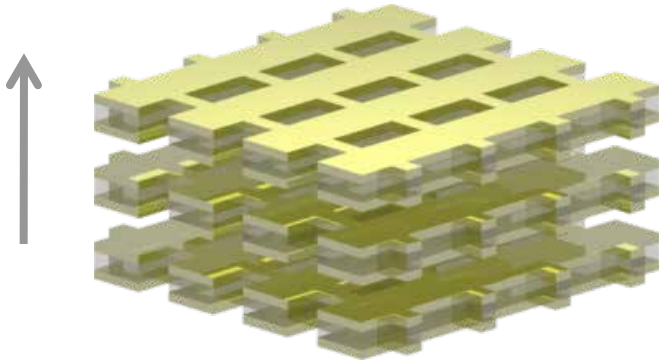
Decker et al., Opt. Lett. ***35****, 1593 (2010)*

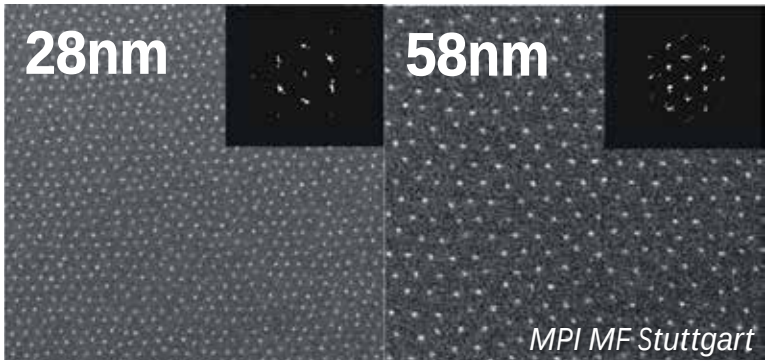
2006 2007 2008 2009 2010

three-dimensional structures
complex optical properties
connected to symmetry of geometry


(Bio)Chemistry
Nano
Material
mm
µm
nm
o
A
Physics

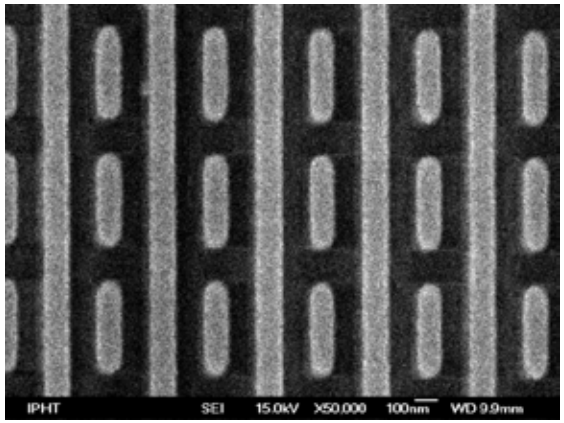


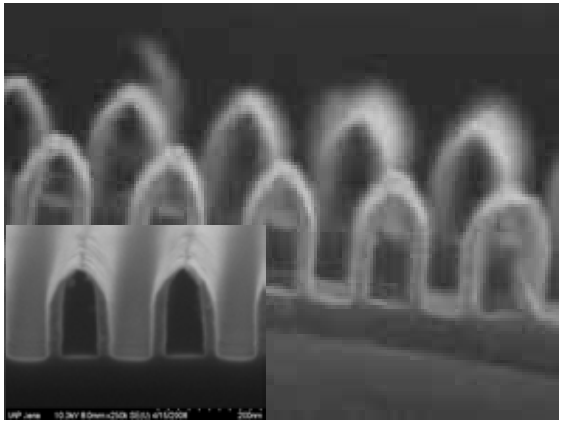


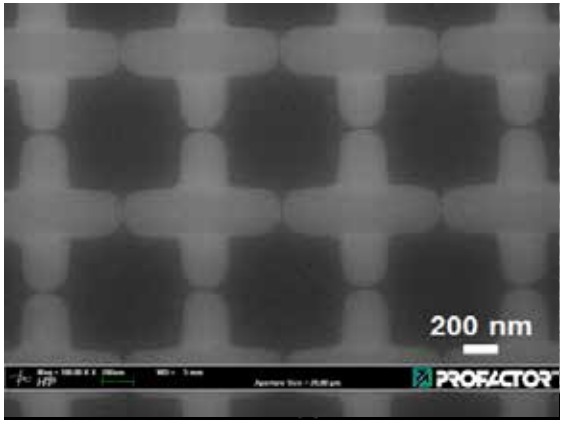

28nm
58nm
MPI MF Stuttgart

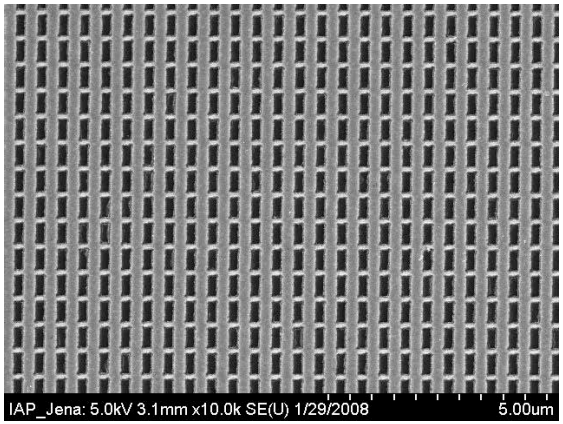
Metamaterials - examples

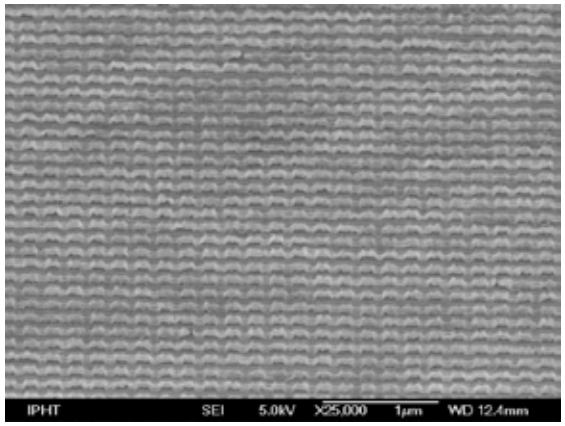
Technology: e-beam nano lithography è planar (single layer)

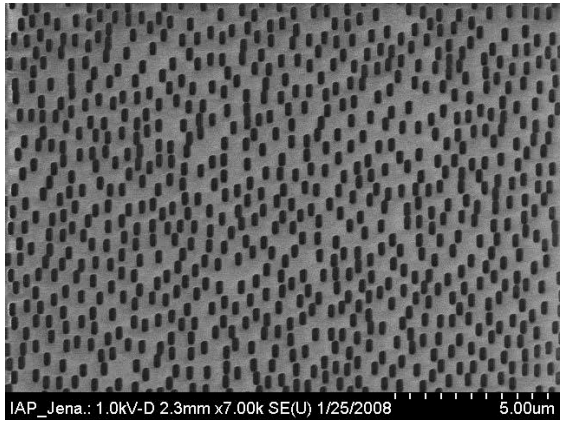






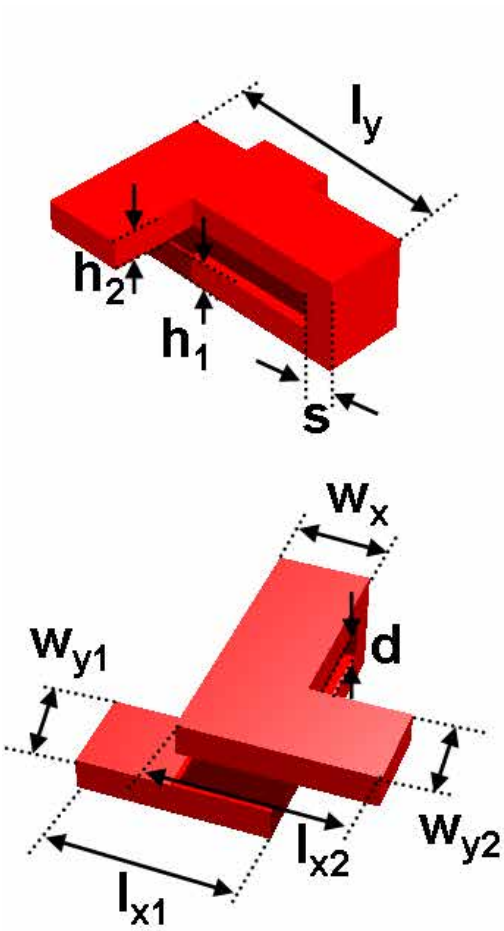


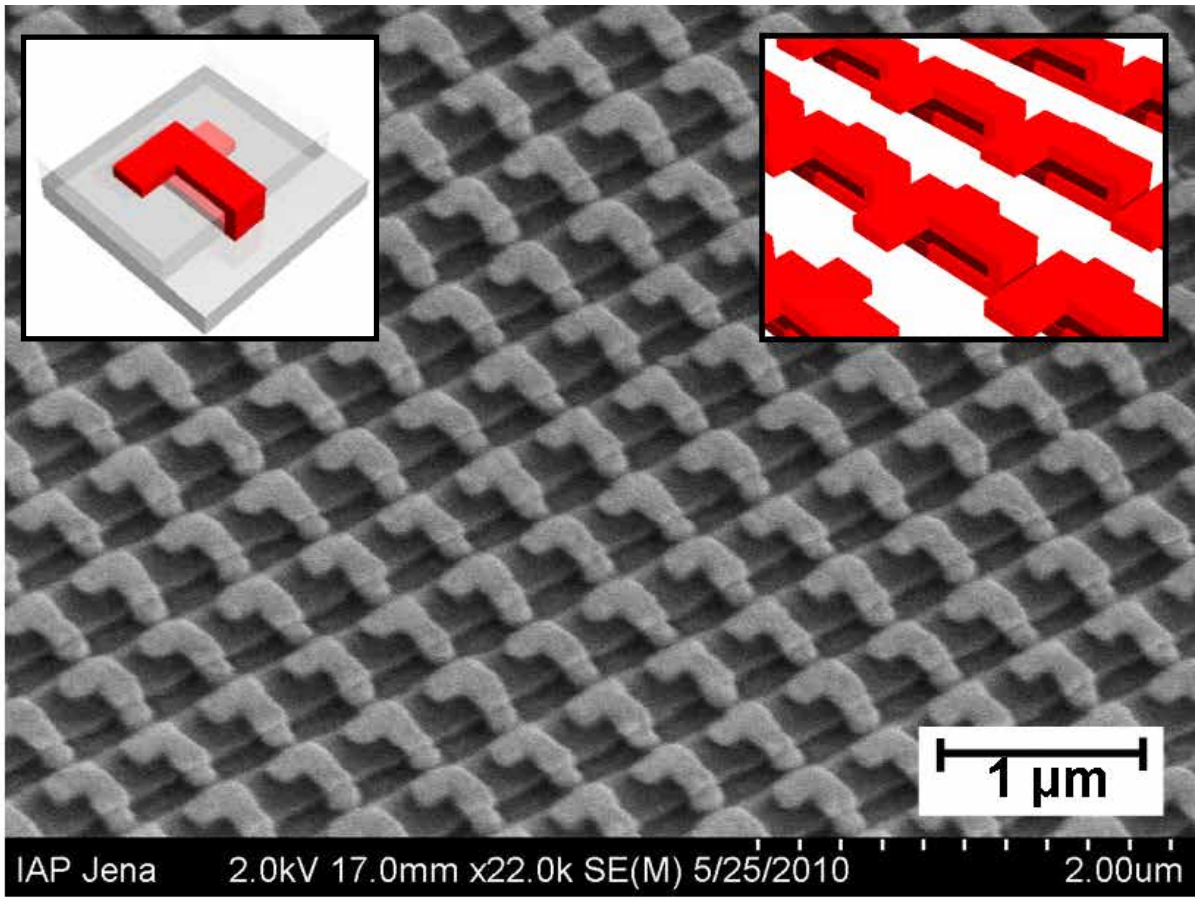




Loop-wire particle

SEM image at oblique view



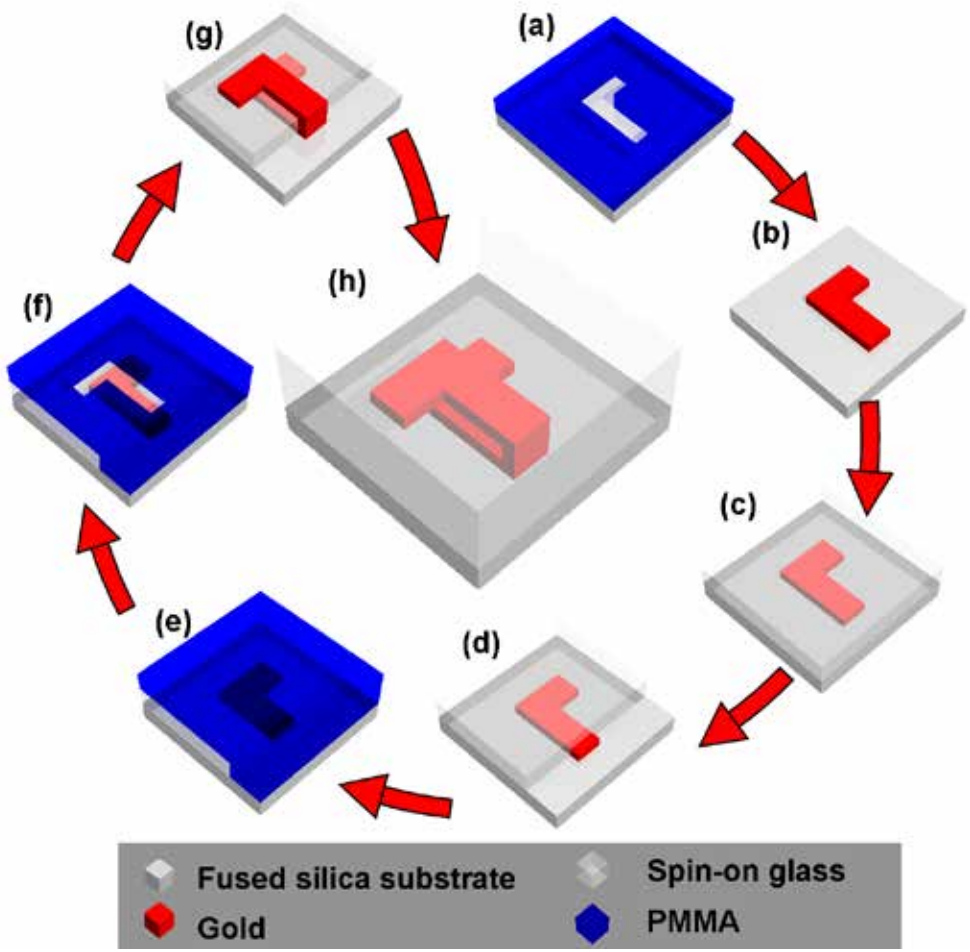


Period$_{x,y}$= 500 nm, l_{x1} = 280 nm, l_{x2} = 290 nm, l_y = 420 nm, w_x = w_{y1}= w_{y2} = 155 nm, h_1 = h_2 = 50 nm, d = 60 nm, s = 50nm.

*Helgert, C. et al. Nano Letters **11**, 4400-4 (2011).*

Loop-wire particle

Fabrication of 3D chiral loop-wire metaatoms



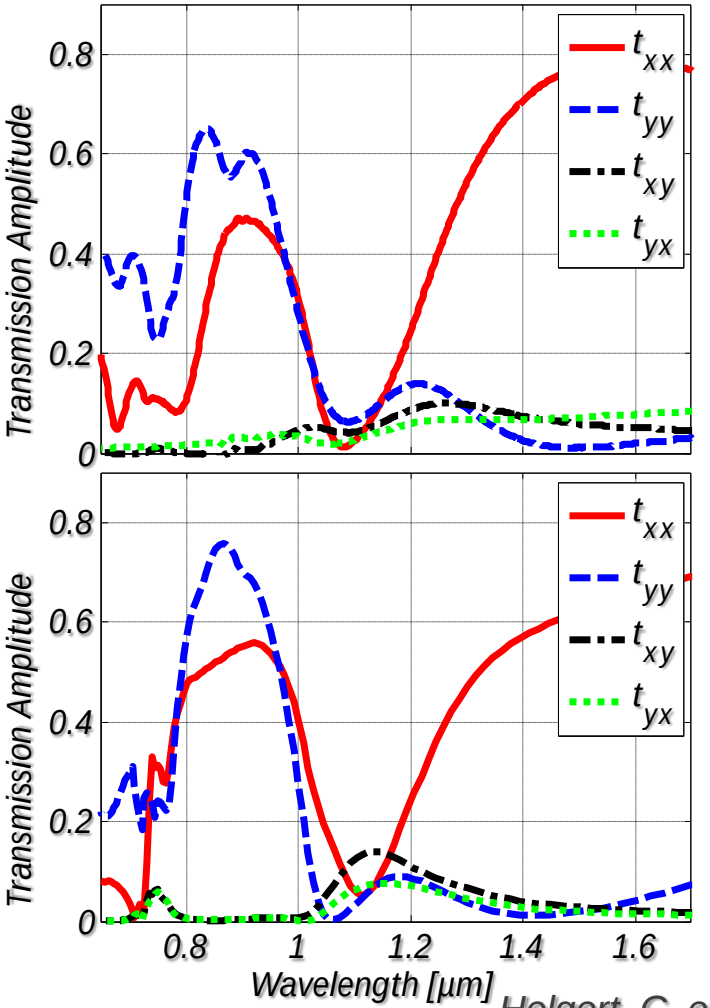
In sum: 3x e-beam lithography with lateral alignment [a,d,f], 2x lift-off [b, g], 3x reactive ion beam etching [d], 5x spin-coating [a,c,d,e,h]

*Helgert, C. et al. Nano Letters **11**, 4400-4 (2011).*

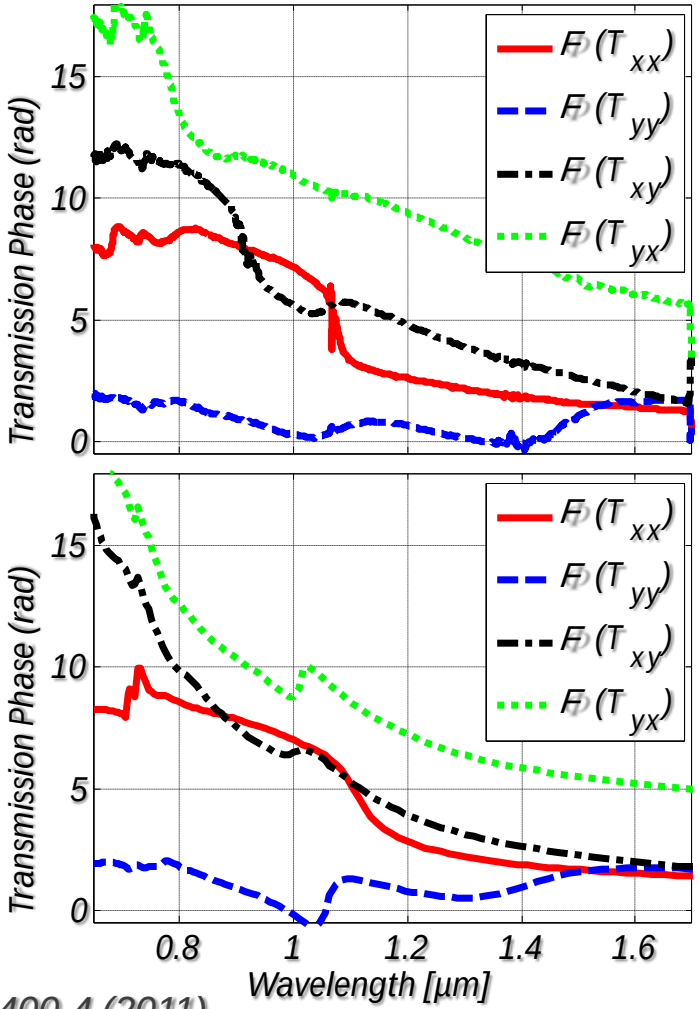
Loop-wire particle

Experimental and numerical results

Transmission amplitudes



Transmission phases



Helgert, C. et al. Nano Letters **11**, 4400-4 (2011).

Chirale Metaatome für hohe optische Aktivität

Vergleich mit natürlichen Medien

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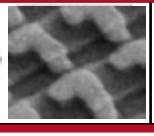
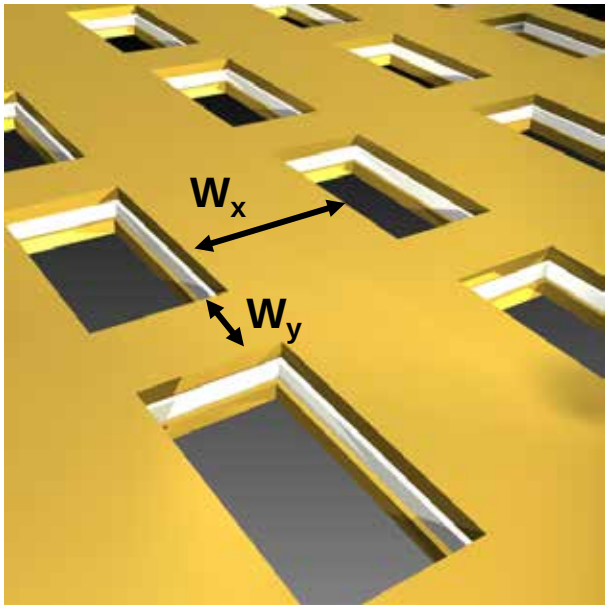
Optisch aktives Material	f	f / Dicke	l
kristalliner Quarz [1] 		$2.0 \cdot 10^1$ °/mm	VIS
Fluorit (Flussspat) [2] 		$1.5 \cdot 10^2$ °/mm	VIS
Flüssigkristall (cholester. Phase) [3] 		$1.0 \cdot 10^3$ °/mm	VIS
plasmonisches 3D loop-wire Metamaterial [4]  	53°	$3.3 \cdot 10^5$ °/mm	NIR/ VIS

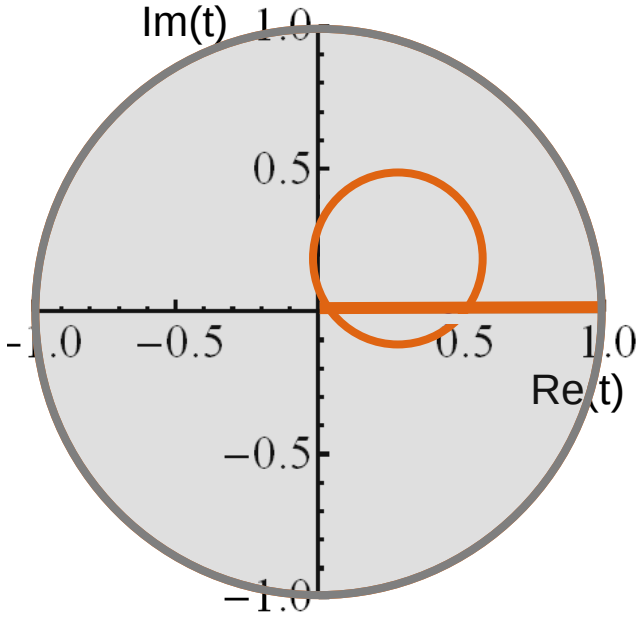
[1] Yeh, Optical Waves in Layerer Media, Wiley, New York (1988).
[2] Young, Kowak, Nature 183, 104 (1959).
[3] de Gennes, The Physics of Liquid Crystals, Clarendon, Oxford Press (1974).
*[4] Helgert et al., Nano Lett. **11**, 4400 (2011).*

Holograms by photonic metamaterials

Fishnet metamaterial



Design wavelength l = 700 nm



Three-layer system:

Au	30 nm
MgO	30 nm
Au	30 nm

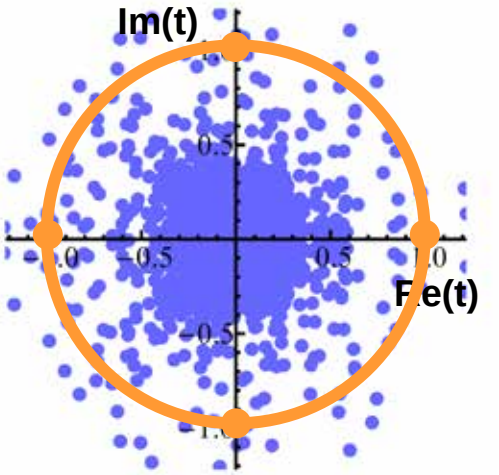
Unit cell size: 600 nm x 600 nm

W_x, W_y: 200 nm … 450 nm in steps of 50 nm

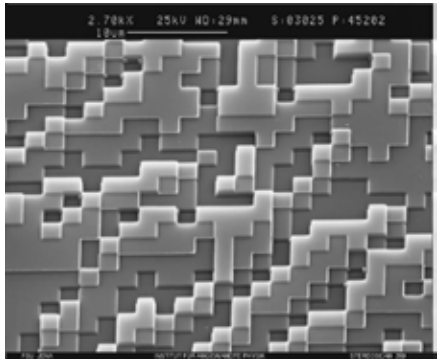
Transmission computed with Fourier Modal Method (FMM) using periodic boundary conditions

Computer-Generated Holograms

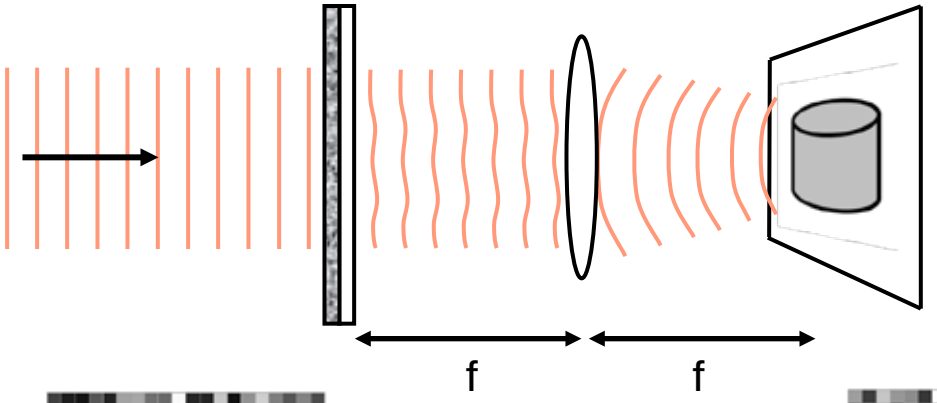
Fourier plane histogram

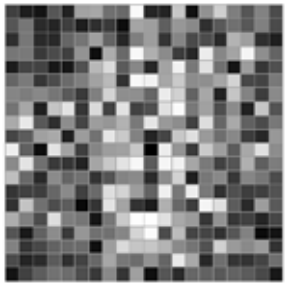


Dielectric height profile



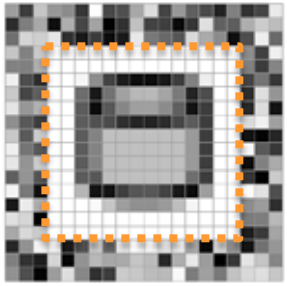
Projection of a real image





Amplitude

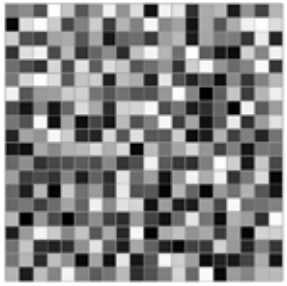
Fourier transform



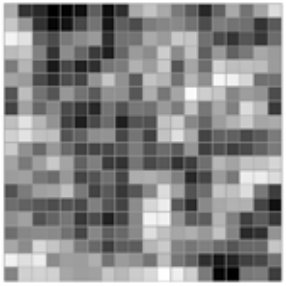
Intensity

Iterative Fourier Transform Algorithm (IFTA)

- Noise freedom
- Phase freedom

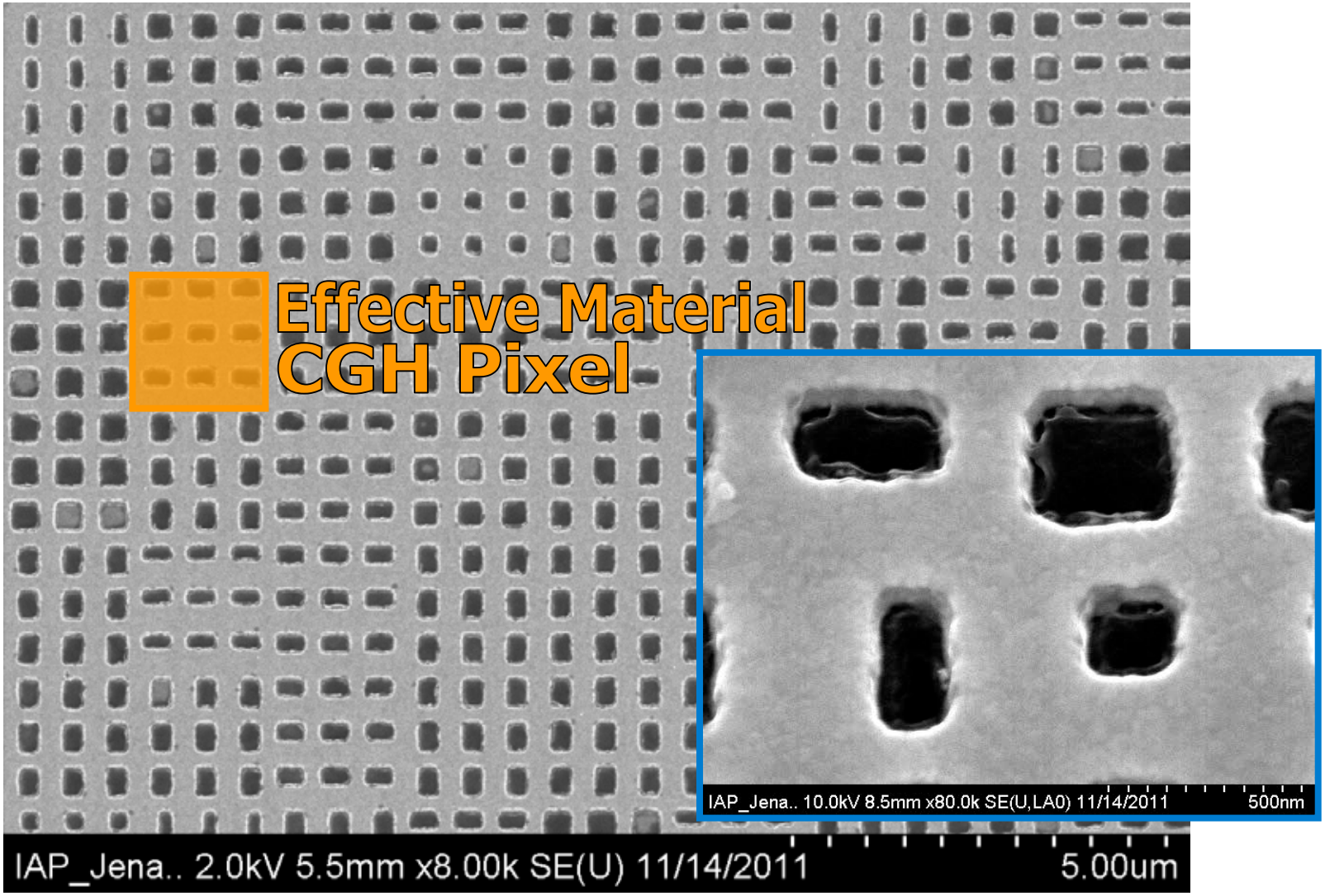


Phase

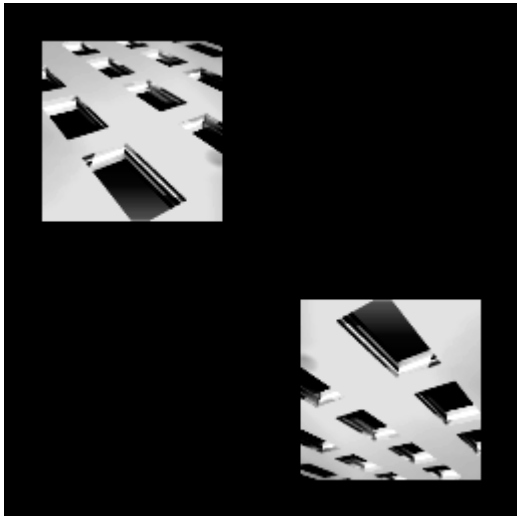


Phase

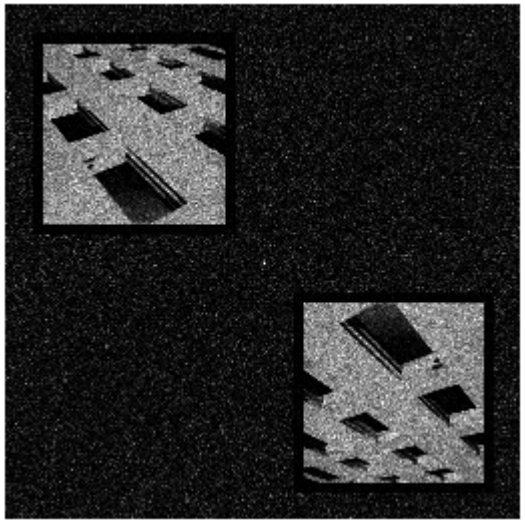
Metamaterial-based CGHs



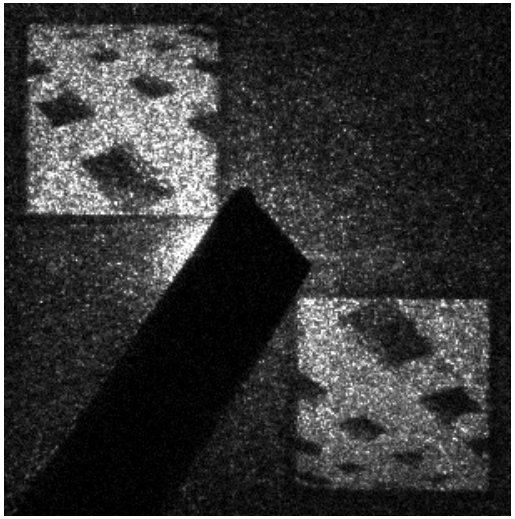
Single-Wavelength Hologram



Target Image
256 x 256 Pixels

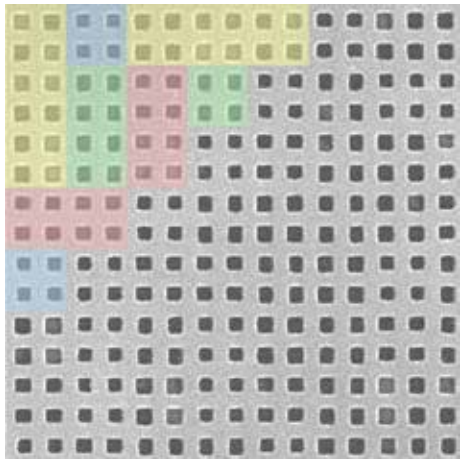
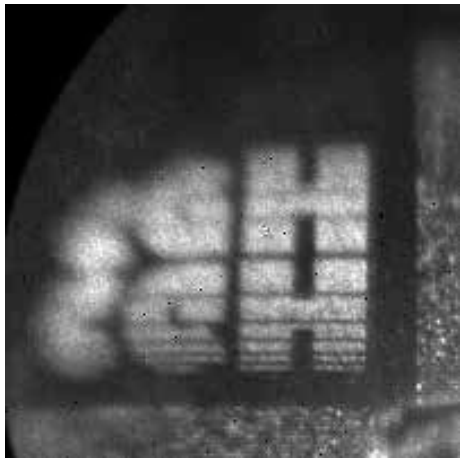
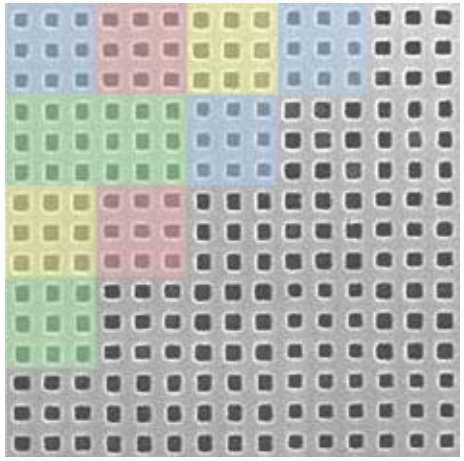
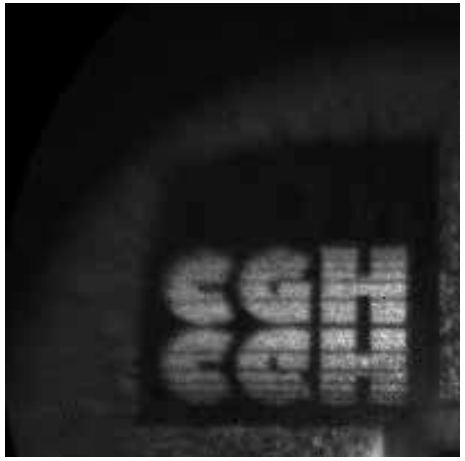


After IFTA
SNR = 43.4



Experiment
l = 700 nm (<200mW)
Fishnet unit cells m = 3

Two Wavelengths - Experiment

		λ_1 = 905 nm	λ_2 = 1385 nm
2 x 2			
3 x 3			

Photonic Nanomaterials =

à Polarization Control

à Computer-Generated Holograms

à …