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Talbot Focusing - a new effect of periodic structures and its utilization

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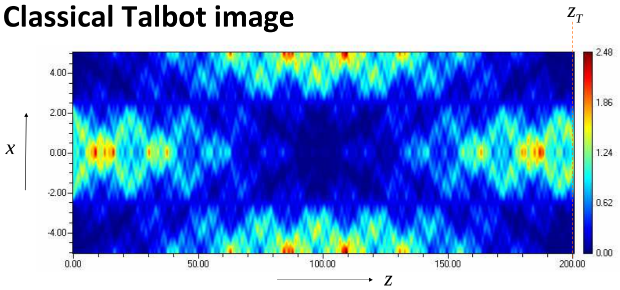
Overview

The Talbot effect is a well known phenomenon of self imaging, indicating that either an amplitude or a phase distribution is replicated at the Talbot distance. Also for special distributions, Talbot imaging was observed at fractional Talbot distances [1]. Talbot Focusing is a new effect, by which a highly concentrated focal spot appears at a particular distance from the periodic optical element. With this effect, the spot diameter is independent of the structure period and the focal length, enabling high NA-foci with large working distance or which are placed very dense.

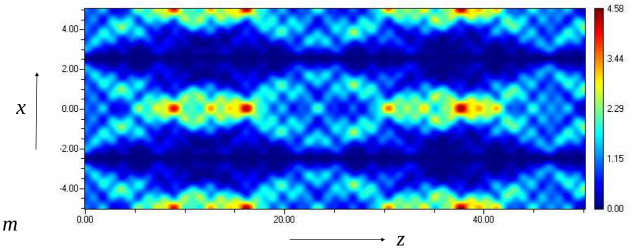
Classical Talbot image



Intensity behind an amplitude Ronchi-grating

At the Talbot distance, $z_T = \frac{2P^2}{\lambda}$ an image of the initial distribution appears.

Talbot Focusing



$P = 10\mu m$

$\lambda = 1\mu m$

Intensity behind a phase Ronchi-grating

At distances smaller than the Talbot distance, focal spots appear on the optical axis. The spot size is smaller than $2\lambda f / P$.

Theory of Talbot Focusing

The complex on-axis amplitude is given by:

$$u_z(0,0) = \sum_{n,m} U_{n,m}^{(0)} \exp\left(4\pi i \varsigma \Lambda \sqrt{\Lambda^2 - n^2 - m^2}\right)$$

$U_{n,m}^{(0)}$: Fourier-coefficients of the element

$\varsigma = z / z_T$: Relative propagation distance

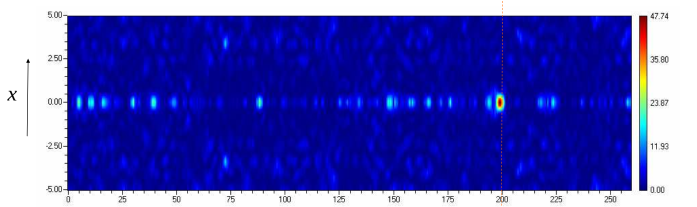
$\Lambda = P / \lambda$: Relative period of the element

Stallinga-Optimization [2]:

$$U_{n,m}^{(opt)} = \mathfrak{F}^{-1} \mathfrak{B}_\varepsilon \mathfrak{F}\left(\exp\left(-4\pi i \varsigma_f \Lambda \sqrt{\Lambda^2 - n^2 - m^2}\right) P_{n,m}(\nu,\mu)\right)$$

$$P_{n,m}(\nu,\mu) = \begin{cases} \delta(\nu - n/P)\,\delta(\mu - m/P) & \text{if } \sqrt{n^2+m^2} < \Lambda \cdot NA \\ 0 & \text{otherwise} \end{cases}$$

$\mathfrak{B}_\varepsilon(u) = 1 \cdot e^{i\frac{\pi}{2}\operatorname{sign}(\arg(u \exp(i\varepsilon)))}$: Phase binarization operation



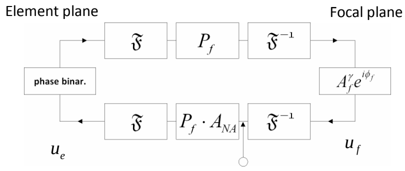
Intensity behind an optimized phase grating (λ = 1µm, P = 10µm, z_f = 200µm, NA = 0.7)

Note: The spot diameter is determined by the *NA* – not by the focal length *f* or by the grating period *P*.

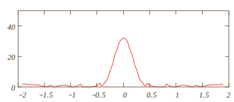
[1] A. W. Lohmann, "An array illuminator based on the Talbot effect", Optik, 79 , 41 – 45 (1988)
[2] S. Stallinga, "High-NA diffractive array illuminators", EOS Topical meeting on Diffractive Optics, 2012 Delft, No. 4932.

Iterative Optimization:

By iteratively applying a phase binarization and a gamma correction, the element can be optimized.
Example: λ = 0.63µm, P = 4µm, z_f = 200µm, NA = 0.9

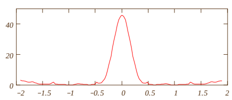


Focal intensity



I_f after one Iteration

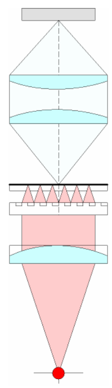
Focal intensity



I_f after 10 Iterations

Applications

Parallel scanning microscope [2]

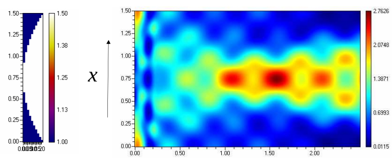


The scan range is only over the sub-cell. Large high resolution images can be acquired fast.

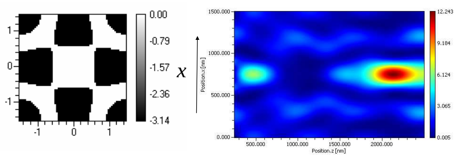
Light concentration on detectors

With decreasing pixel size, micro lenses are less suitable for light concentration on detector pixels.
Example: *P = 1.5µm, λ = 0.5µm*

Micro lens: (RCWA-Calculation)



Talbot focus: (RCWA-Calculation)



Structure I(x, z)

Conclusion

With Talbot Focusing, an array of focal spots can be generated. The resolution is only determined by the selected NA and not by the cell period or the focal length. Possible applications are in scanning microscopy or in light concentration for detector arrays.

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