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Exploring new data channels in optical data storage

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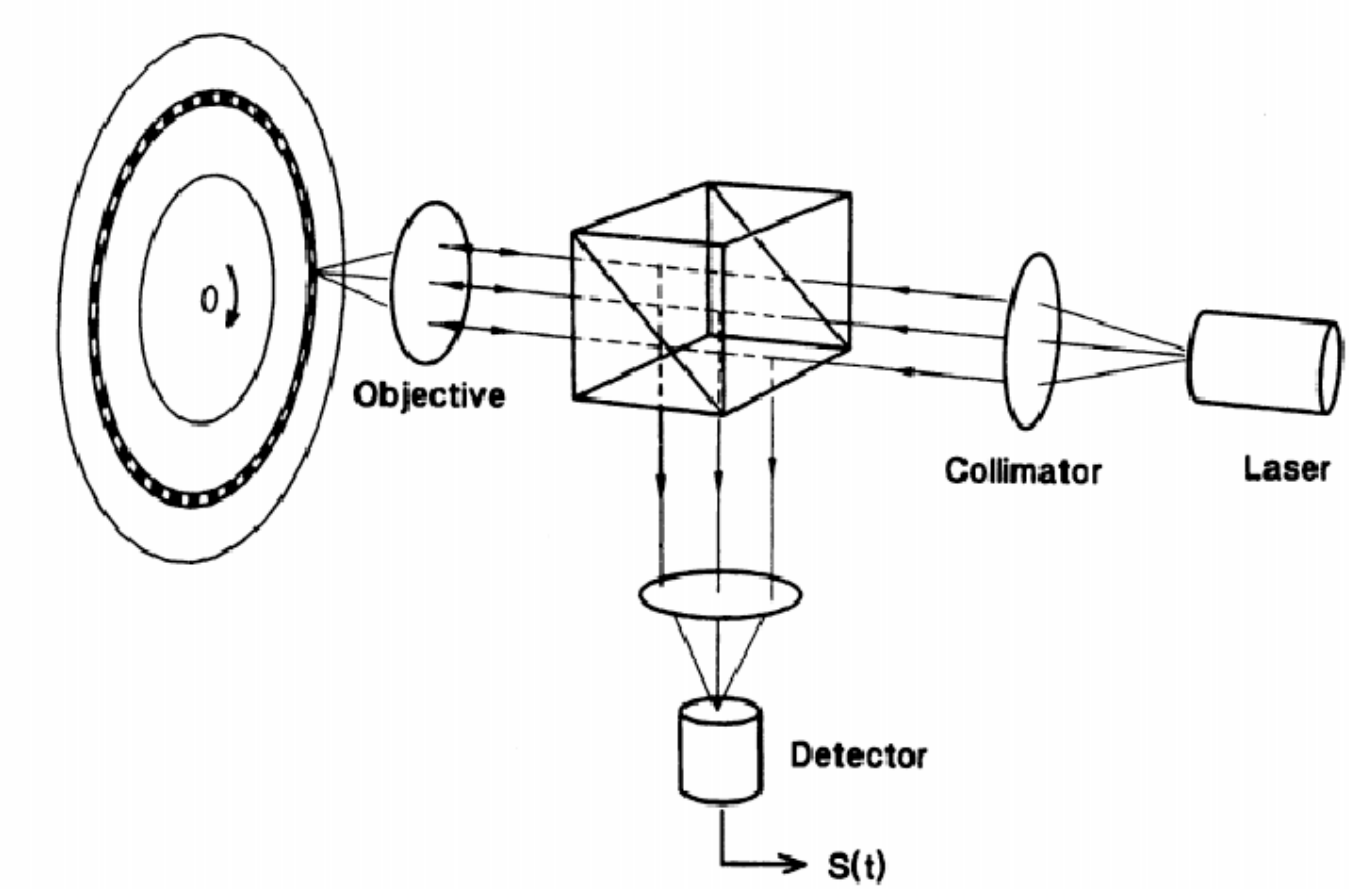
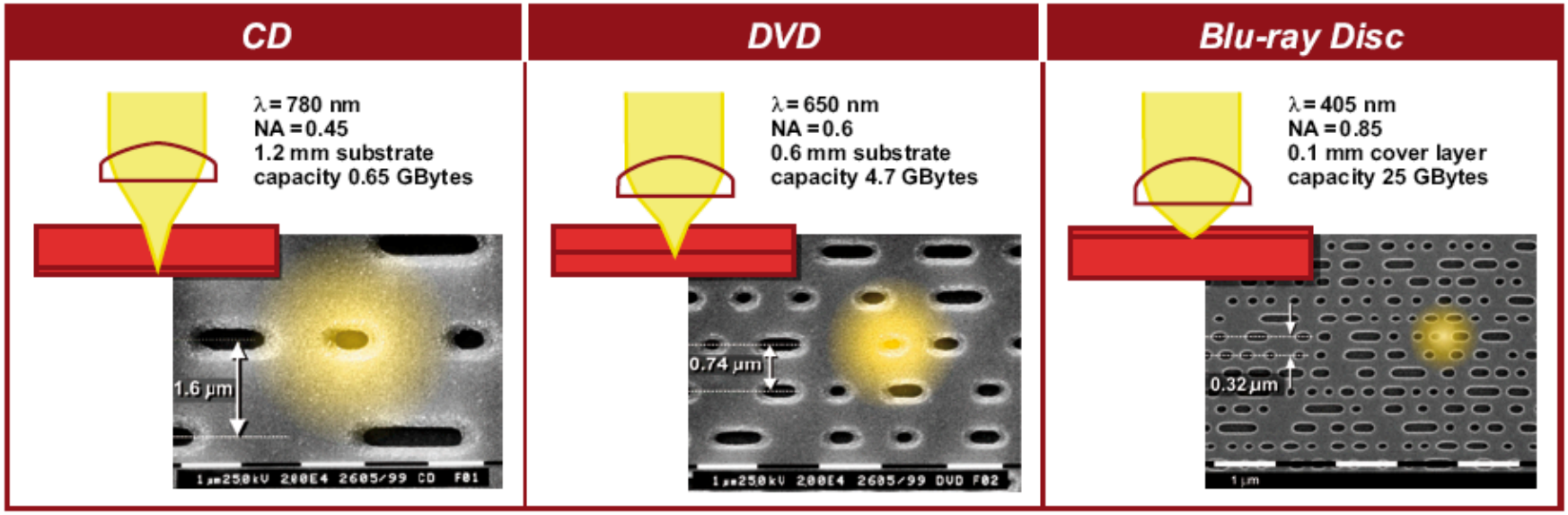
Ouline

- Short introduction of optical recording
- Present options for the next generation
- Multiplexing approach
- Quantum noise

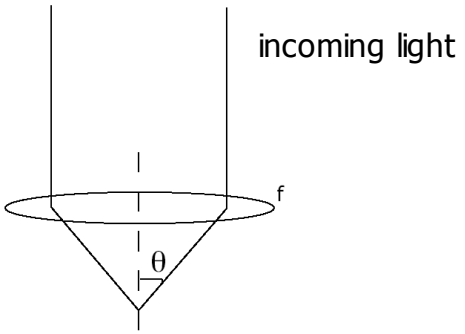
General Description of the compact disk



Three generations



Spot size 0.5 λ/NA
NA= numerical aperture = n sinθ



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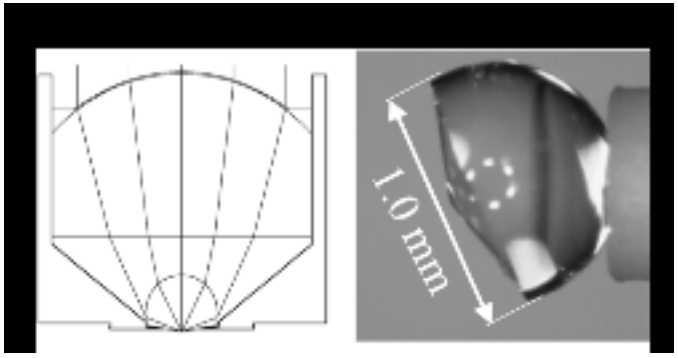
Fourth generation?

- Near field optical recording



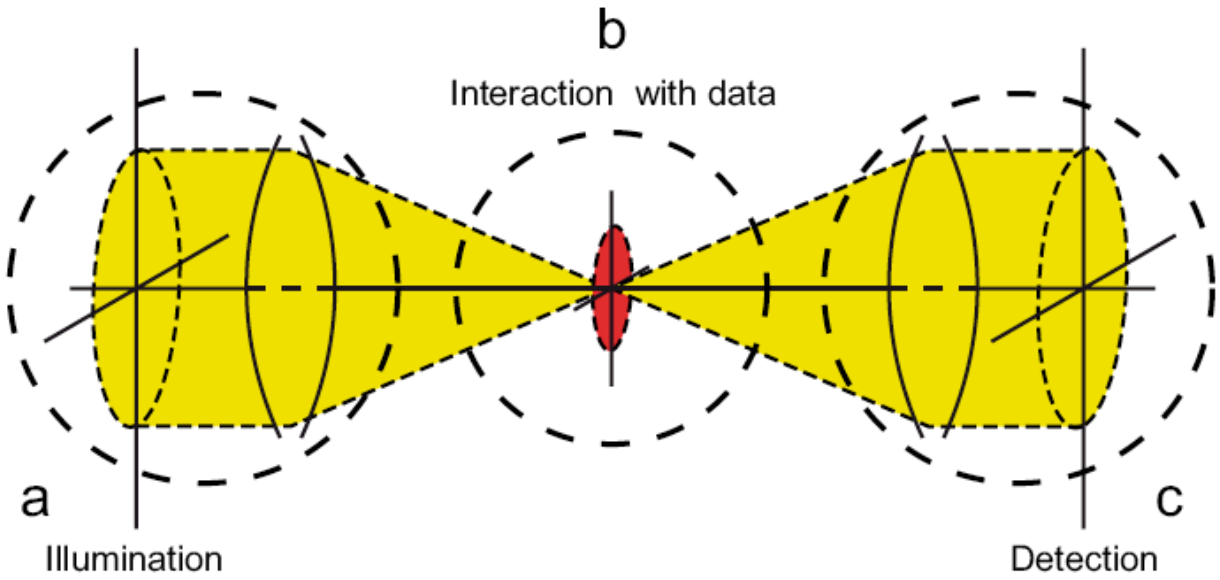
Numerical aperture = 1.9
Disk scans about 25- 30 nm from lens
50 GBytes on a single layer

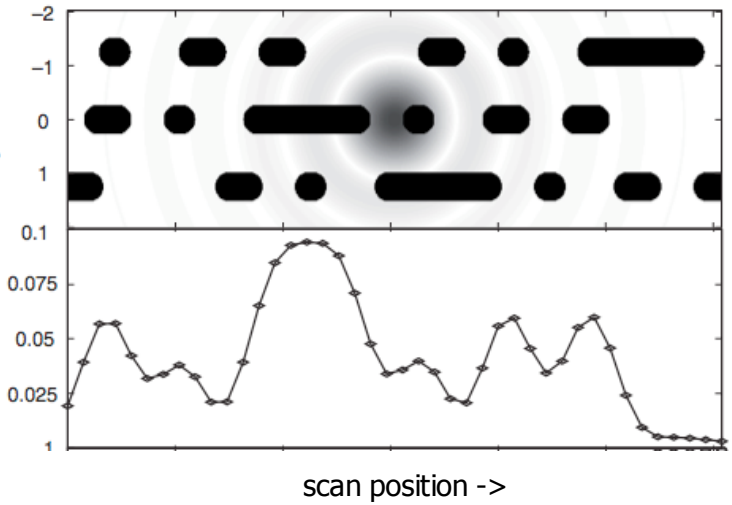
F. Zijp et al, High density near field optical recording with solid immersion lens conventional actuator and a robust air gap servo, IEEE trans. on Magn. 41, 1042 (2006)

- Multiplexing (this talk)

Far field detection
More information on a single pit

Theoretical approach to the CD problem





scan position ->

Light scattered from a structure

Light

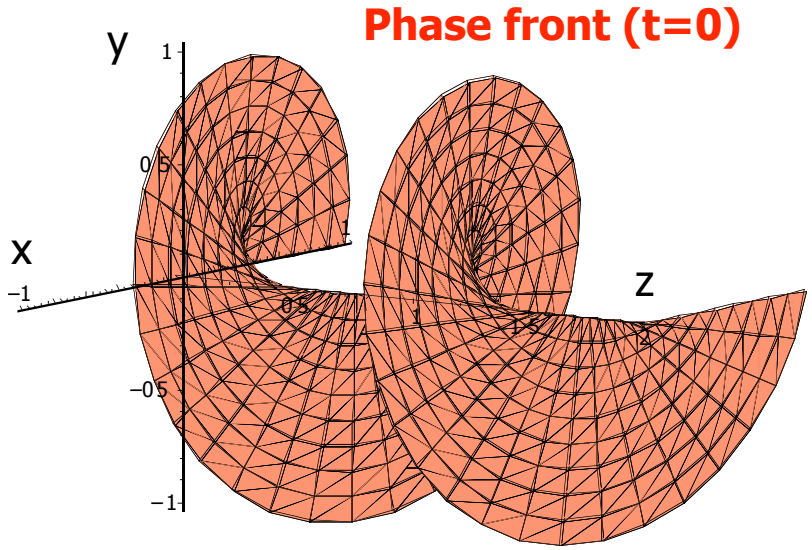
- intensity and amplitude
- phase
- polarisation

Orbital-angular momentum

- linearly polarised
- helical phase

$$\ell^{+} = e^{i\phi}\hat{x}$$

$$\ell^{-} = e^{-i\phi}\hat{x}$$



Paraxial wave equation -> Gauss-Laguerre modes

Set of modes of the electromagnetic field

$$U_{pl}(r,\phi,z) = \left(\frac{2p!}{\pi(p+|l|)!}\right)^{1/2} \frac{(-1)^p}{w(z)} \left(\frac{2r^2}{w^2(z)}\right)^{|l|/2} L_p^{|l|}\left(\frac{2r^2}{w^2(z)}\right)$$
$$\times \exp\left[-\frac{ikr^2}{2R(z)} - \frac{r^2}{w^2(z)} + ikz + il\phi + i(2p+|l|+1)\arctan\frac{z}{z_R}\right]$$

$$R(z) = \frac{z^2 + z_R^2}{z}$$

$$w(z) = \sqrt{\frac{2\left(z^2 + z_R^2\right)}{kz_R}}$$

p=0, l=0 ⟶ *Gauss mode*

p=0, l=1 ⟶ *Doughnut mode*

Two examples:

1. **angular momentum present in the beam with simple structure (TEM01 bits)**
2. **angular momentum present in the structure with Gauss beam illumination (qss)**

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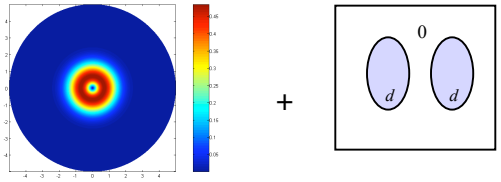
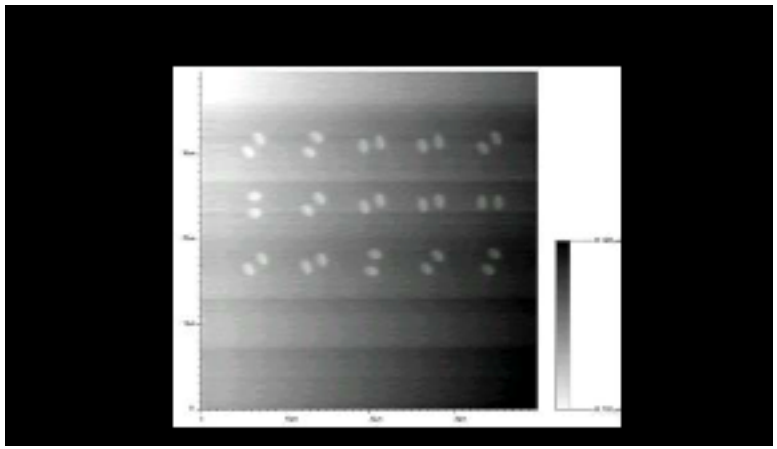
Angular momentum present in the beam with simple structure

"TEM01" bits

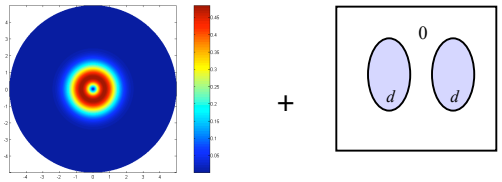




Size of pits to be read with NA=0.5

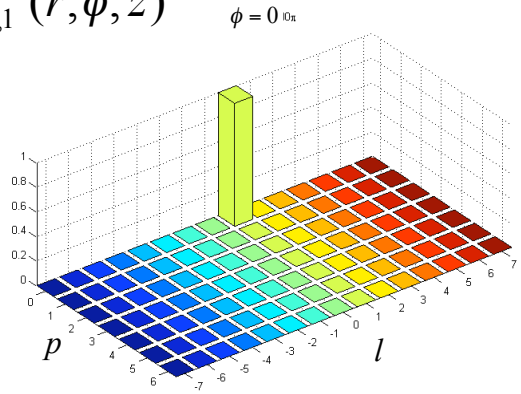
Angle, depth and size of pits are variables

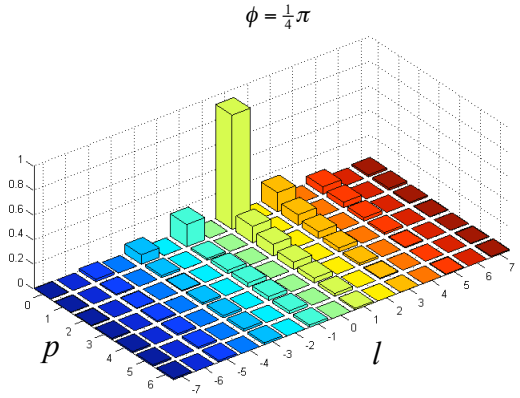
TEM$_{01}$ bits, depth multiplexing

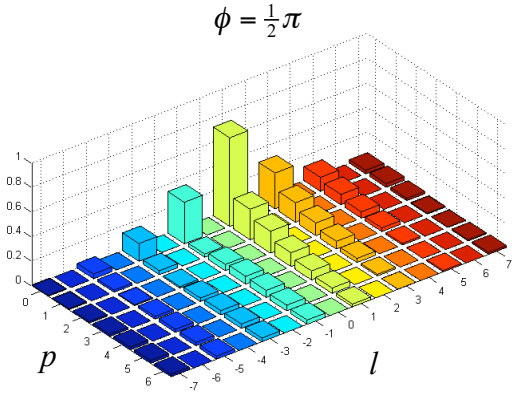


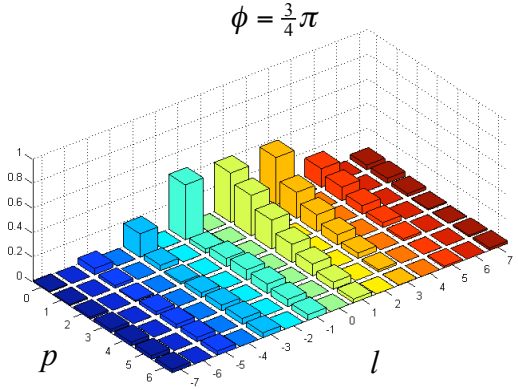
$$\phi = 2\pi \frac{2d}{\lambda}$$

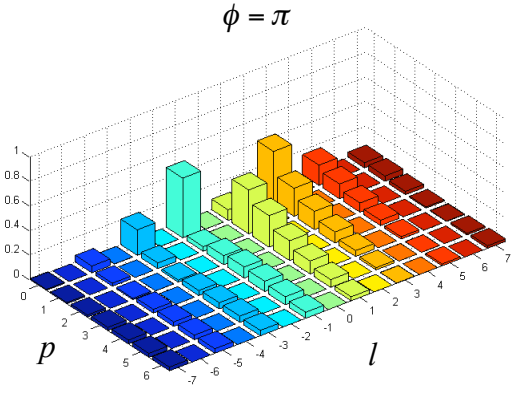
$$U_{0,1}^{LG}(r,\phi,z)$$

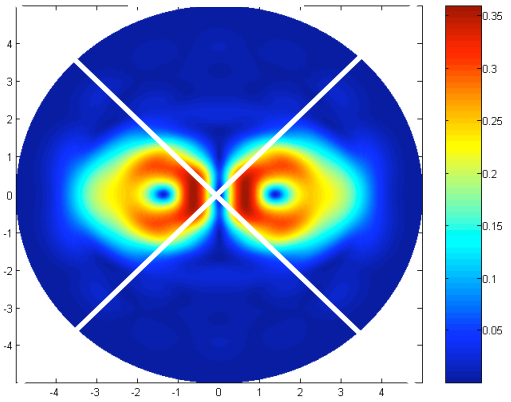




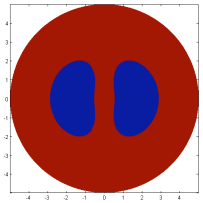




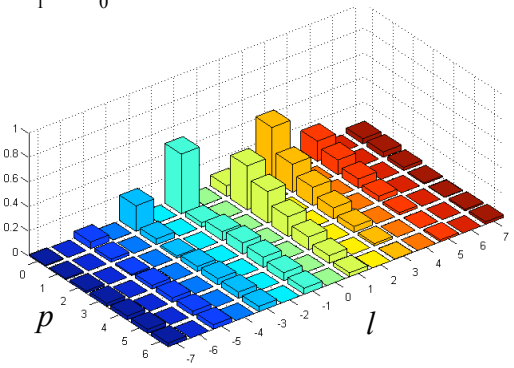


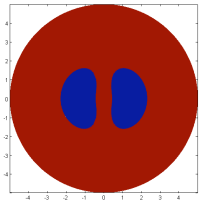


TEM_{01} bits, size multiplexing

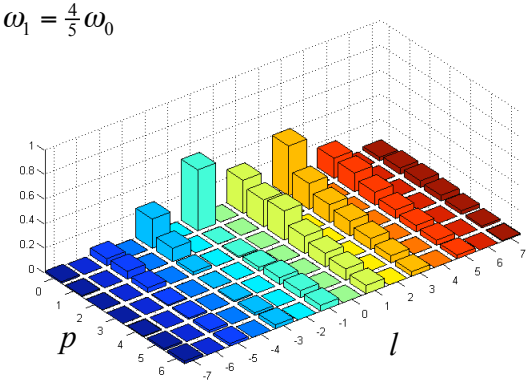


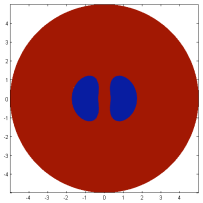
$\omega_1 = \omega_0$



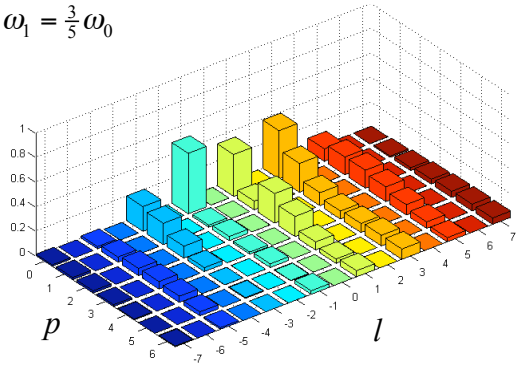


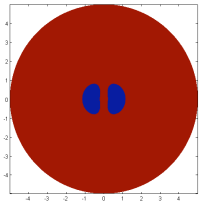
$\omega_1 = \frac{4}{5}\omega_0$



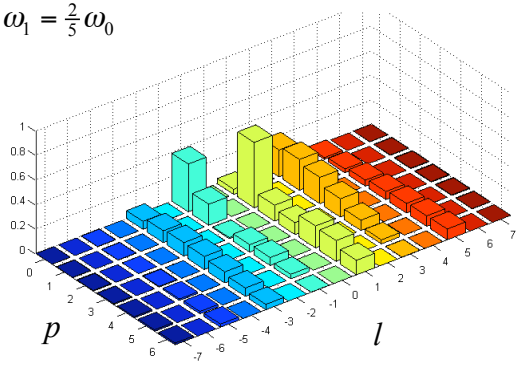


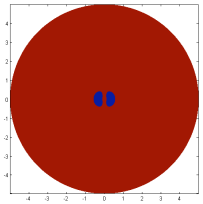
$\omega_1 = \frac{3}{5}\omega_0$



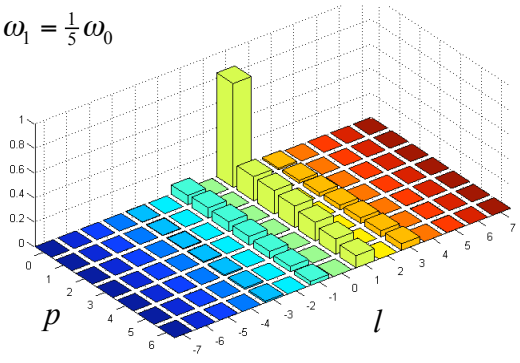


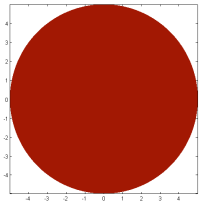
$\omega_1 = \frac{2}{5}\omega_0$



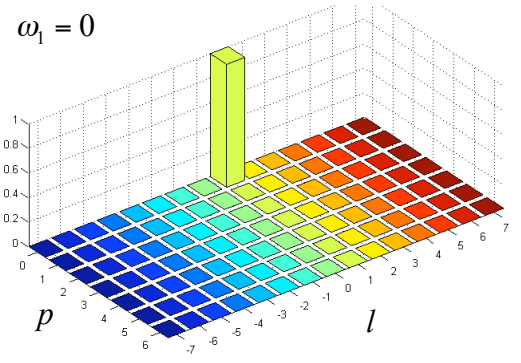


$\omega_1 = \frac{1}{5}\omega_0$

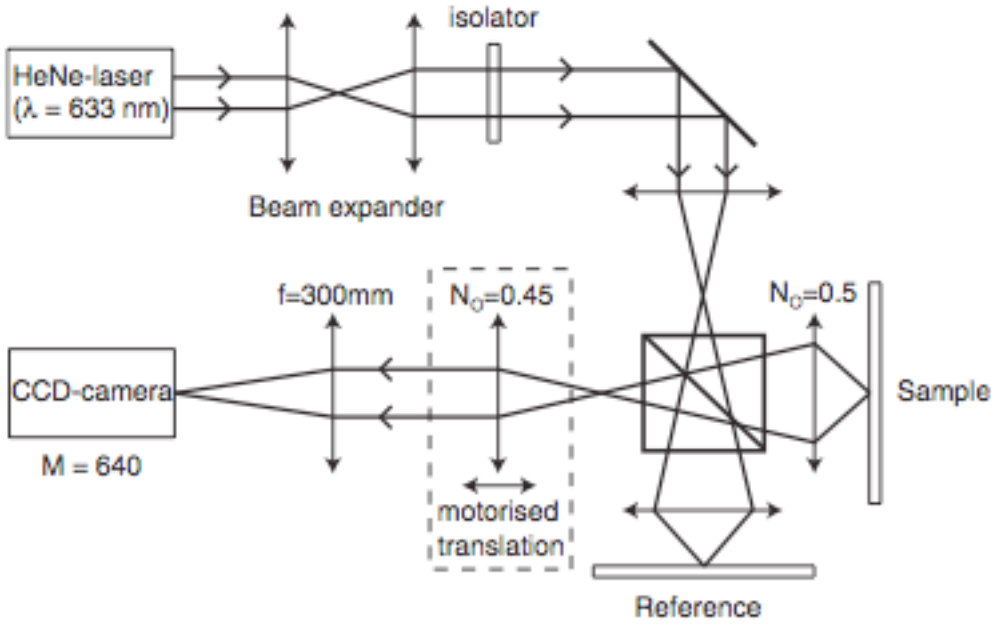


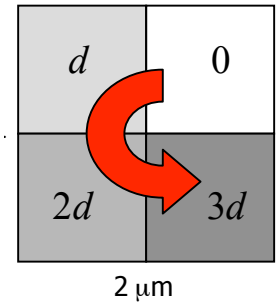


$\omega_1 = 0$



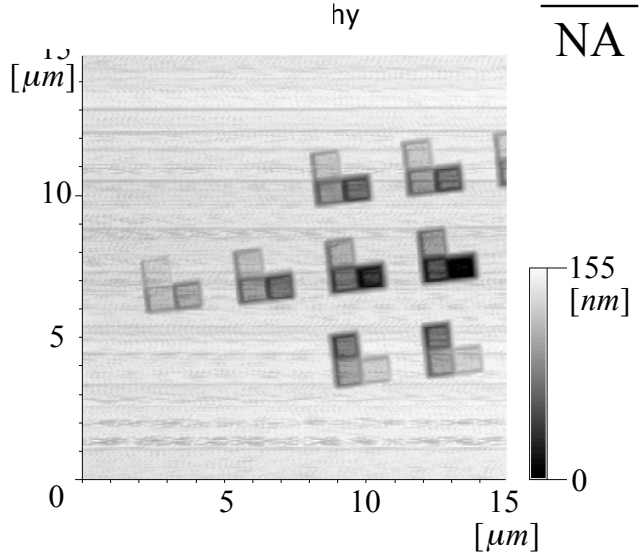
Quadrant staircase structure (qss)





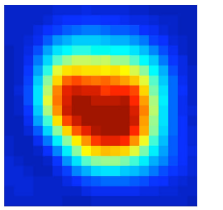
- orientation θ
- depth $\frac{1}{32}\lambda \le d \le \frac{1}{8}\lambda$
- direction $\pm$

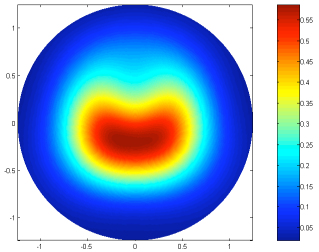
$$\frac{0.6\lambda}{NA}$$



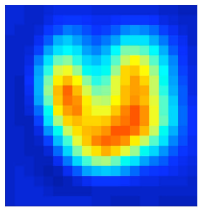
QSS, depth multiplexing

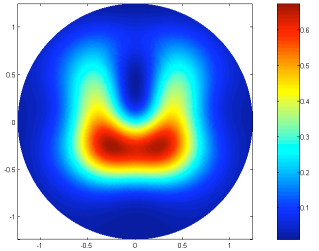
$d = \frac{1}{32}\lambda \rightarrow \phi = \frac{1}{8}\pi$



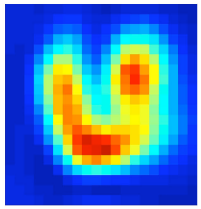


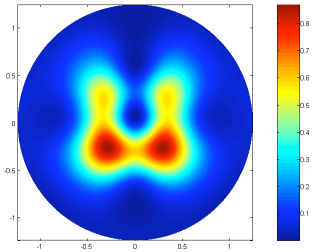
$d = \frac{1}{16}\lambda \rightarrow \phi = \frac{1}{4}\pi$



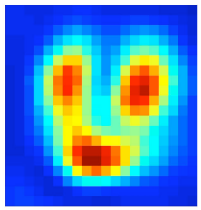


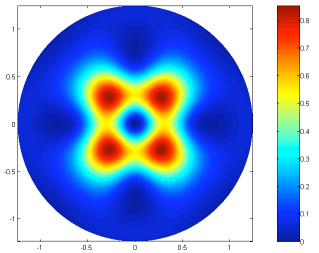
$d = \frac{3}{32}\lambda \rightarrow \phi = \frac{3}{8}\pi$





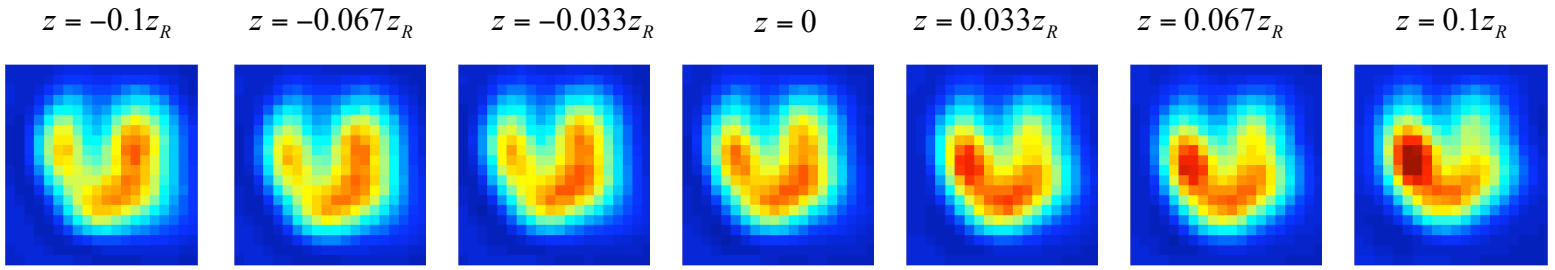
$d = \frac{1}{8}\lambda \rightarrow \phi = \frac{1}{2}\pi$

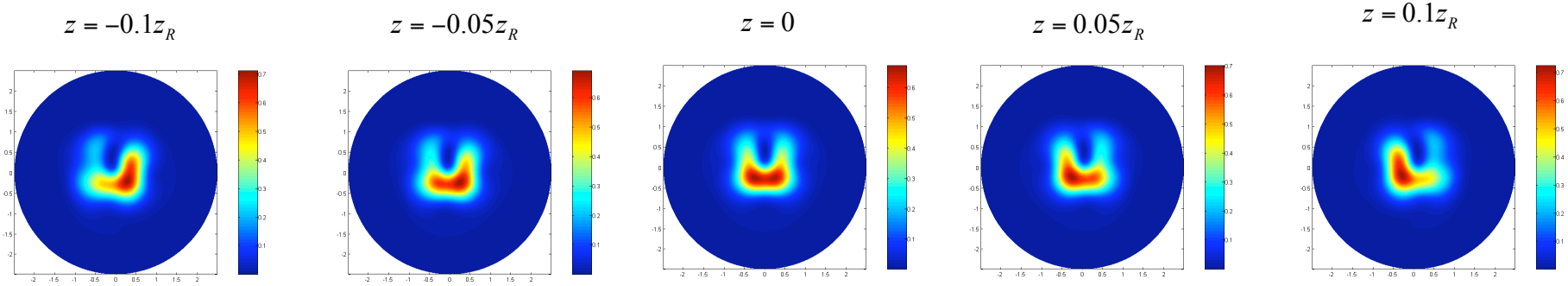




QSS, depth multiplexing

Detection of the directionality

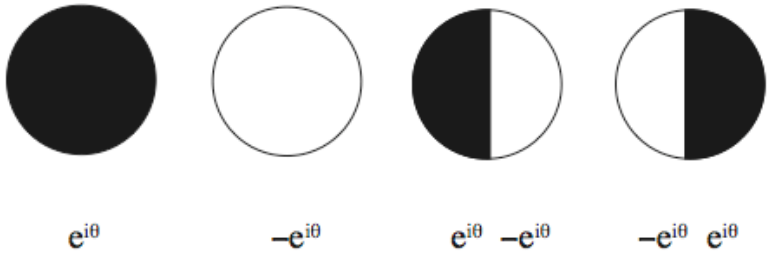




Recent work in Canberra

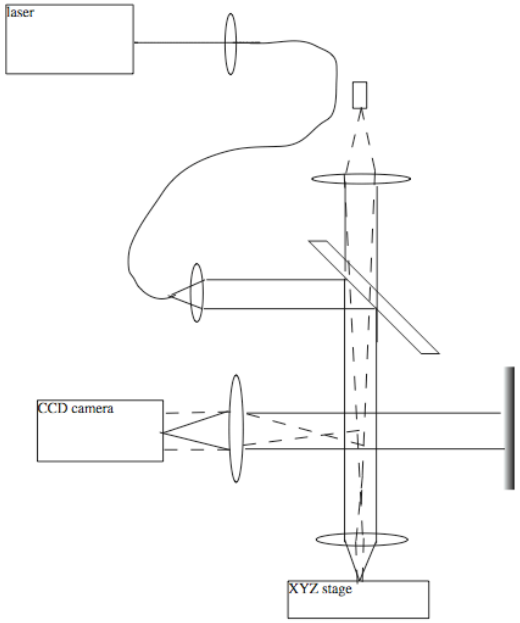
M. Hsu et al., A quantum study of multi-bit phase coding for optical data storage, (J. Ouant. Electronics)

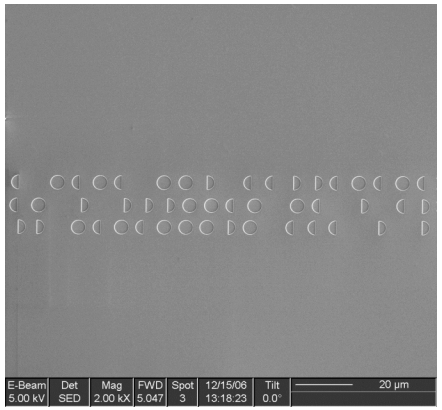
4 possible phase front profiles:

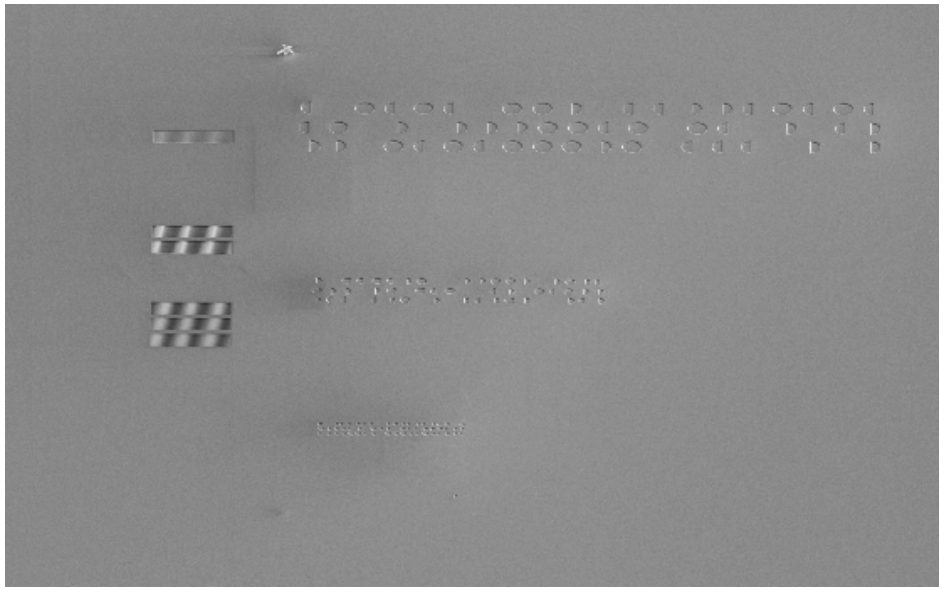


θ =0 to $\lambda/2$

Experimental scheme







Mask:
sizes of single structure=5, 2.5, and 1.25 µm

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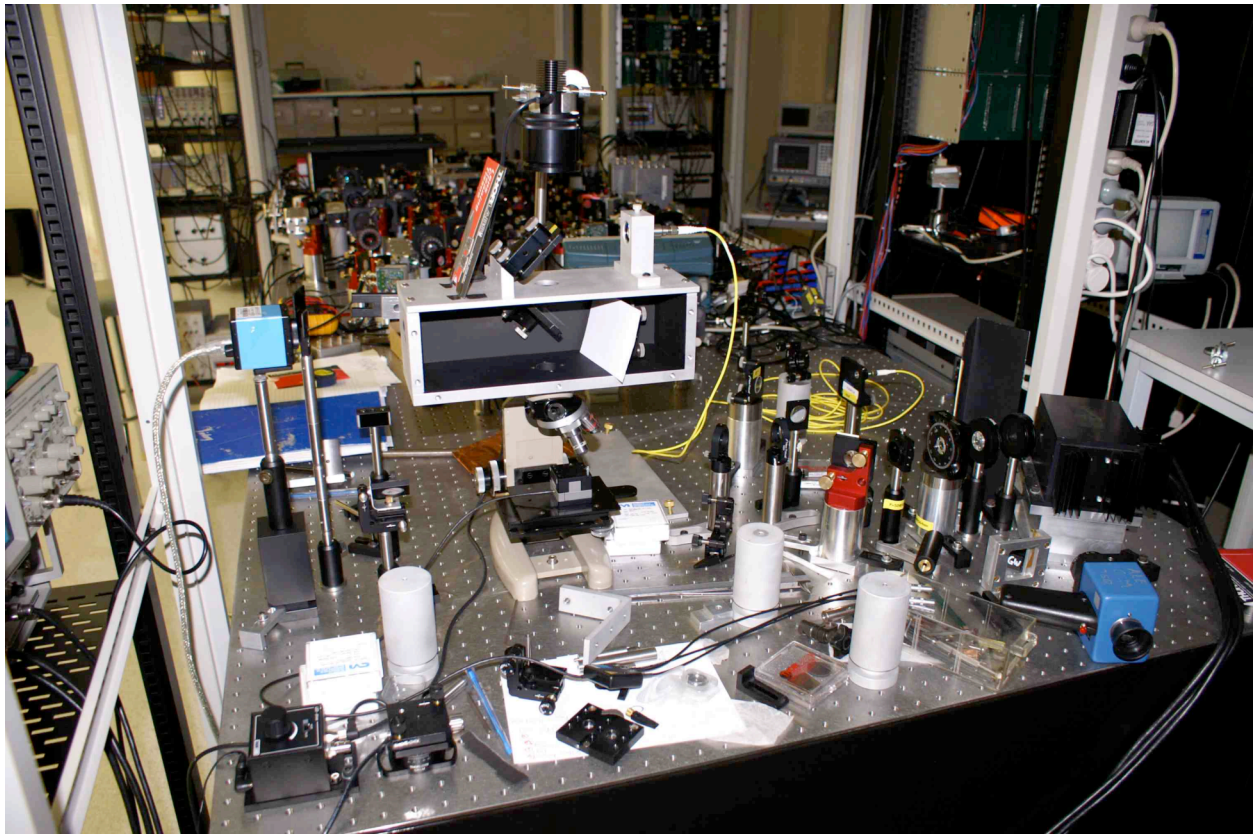
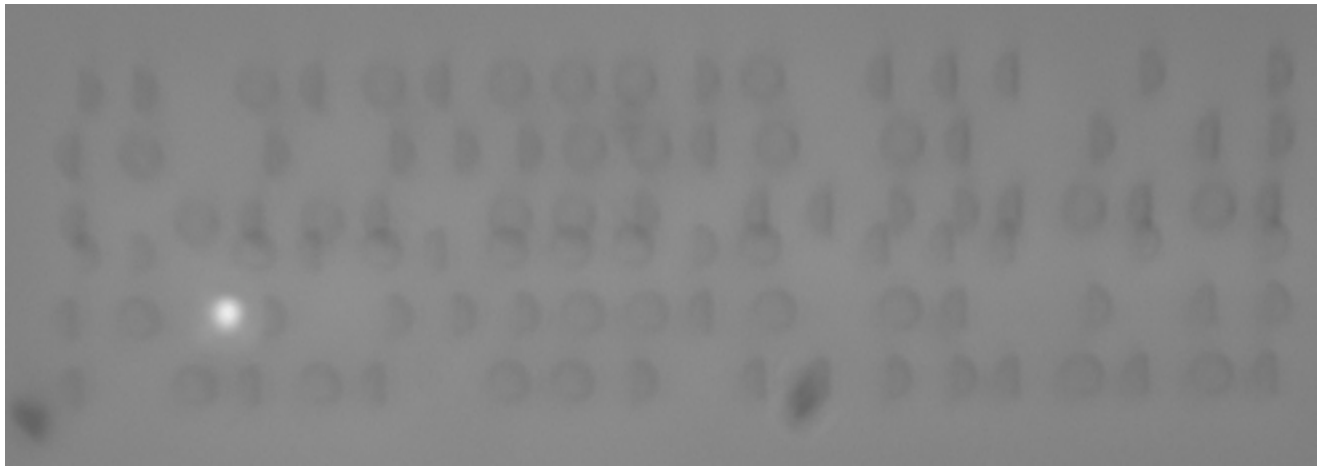
Experimental set-up



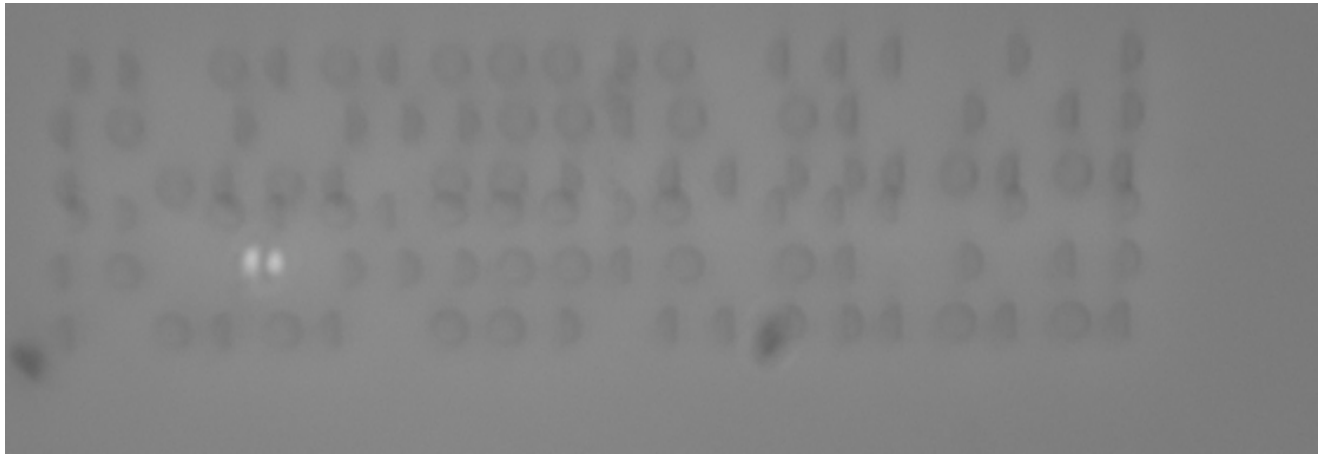
Intensity measurements

Reflected light from the mask at the CCD camera

"full moon" pit



"half moon" pit



Numerical aperture = 0.25 spot size at the structure = 5 μm

Lookout 1

- Phase measurements: depth multiplexing

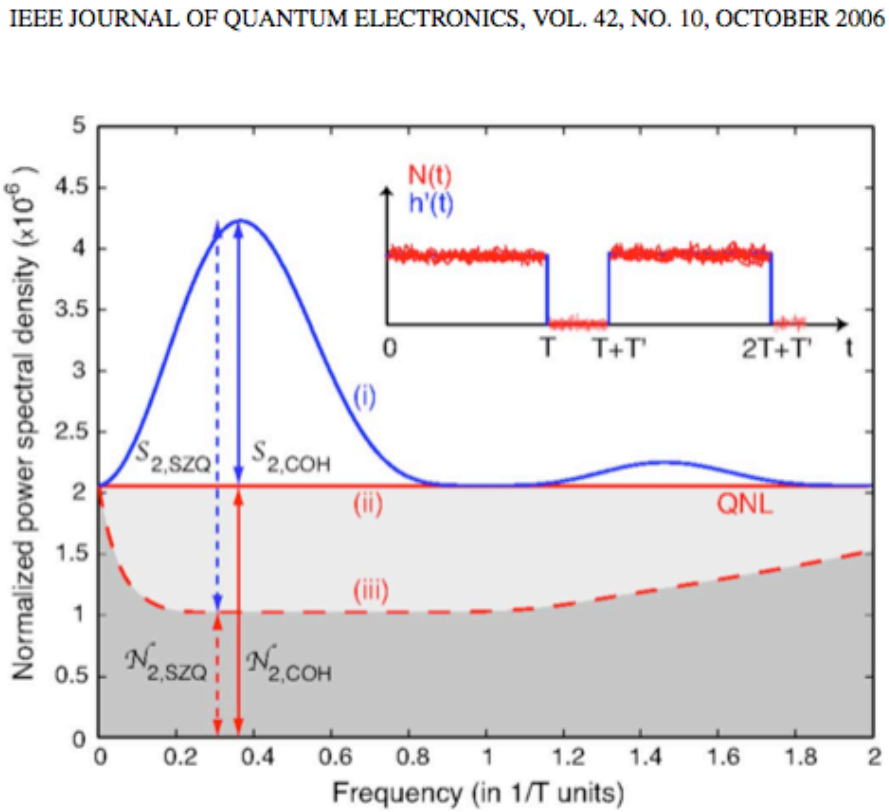
- Detection using split detectors

... and further

Lookout 2

Use detection techniques to reduce the noise

M. Hsu et al.: consecutive pit measurements to shift the center of the signal to a higher frequency so that squeezed light can be used to improve the signal-to-noise ratio



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References:

A. S. van de Nes, S. F. Pereira and J. J. M. Braat
"High density optical data storage"
Rep. Prog. Phys. 69, 2323 (2006)

M. T. L. Hsu, V. Delaubert, W. Bowen, C. Fabre, H. A. Bachor and P. K. Lam
"A quantum study of multi-bit phase coding for optical storage"
J. Quantum Electron. 42, 1001 (2006)