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FDTD Analysis of Readout Characteristics in a near-field MAMMOS recording system

Matthew Manfredonia

Paul Nutter & David Wright

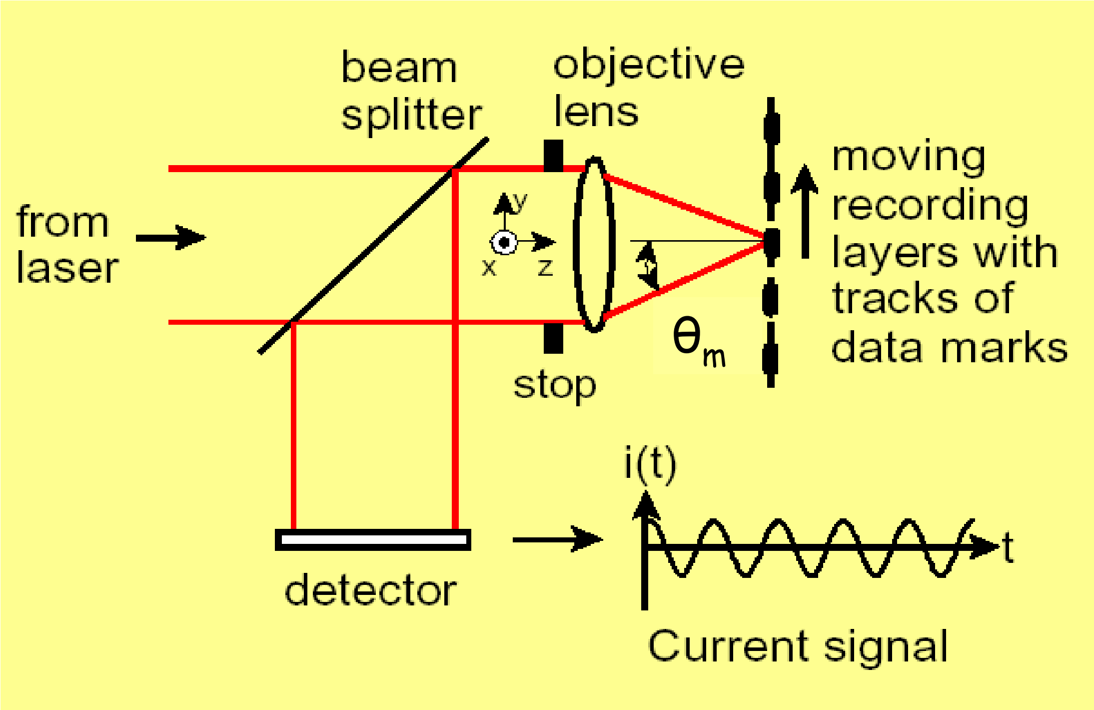
Electronic & Information Storage Systems Research Group
School of Computer Science
University of Manchester

(http://www.cs.man.ac.uk/eissrg/)

Overview

- Introduction
  - Basic Optical Storage System
  - Improving Storage Capacity – MAMMOSIL
- Modelling the Optical Readout Signal
  - Modelling Options
  - Proposed Method
  - Example results
- Conclusion

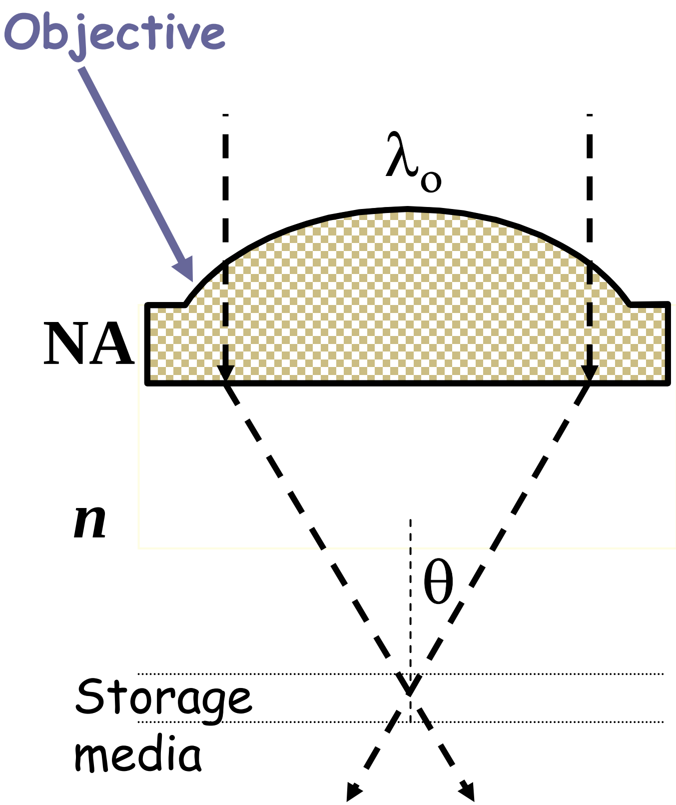
Basic Optical Storage System



- Focussed Laser 'spot' on medium
- Recorded mark reflectivity differs with non-recorded area
- Disc rotation -> reflected light modulation level by mark pattern
- Resulting readout signal

For Improved Resolution…

… we need to decrease the diameter of the optical spot



$$d_s \sim \frac{\lambda_o}{\mathrm{NA}}$$

Hence, traditionally:

1) Decrease λ_o - down to 350nm (UV)
2) Increase NA – $NA_{max} < 1$ (practical maximum ~ 0.9)

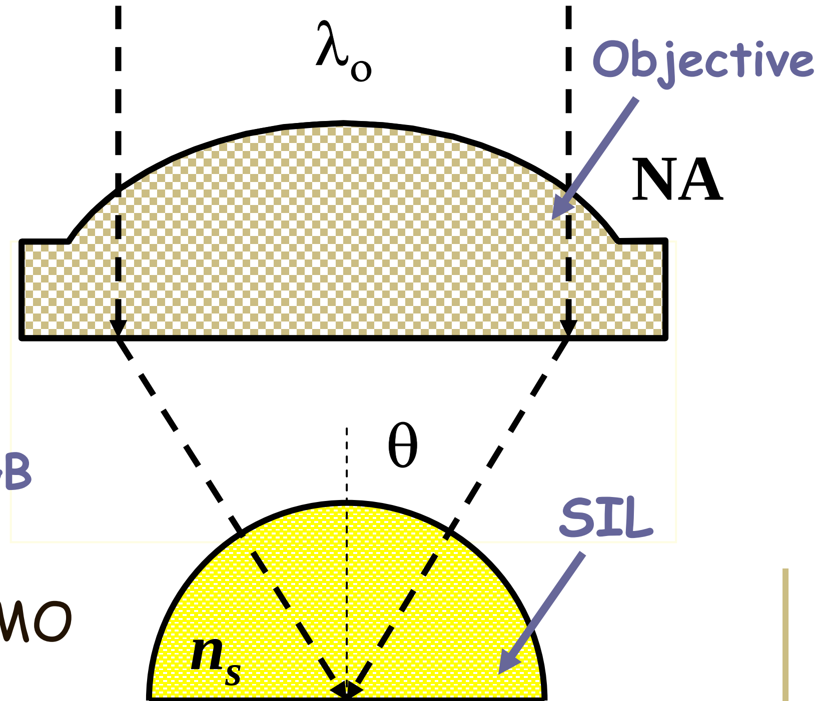
Blueray operates at ~ these limits

…further increase in capacity requires alternative approach

The Solid Immersion Lens

… most basic SIL - hemisphere of high refractive index

$$\lambda_{SIL} \sim \frac{\lambda_o}{n_s}$$



MAMMOSIL = Blue laser +
MAMMOS media + SIL = ~450GB

Possible candidate for future MO storage systems

Major Goal: Simulate MAMMOSIL Readout Signal so that it can be both assessed & optimised

Modelling the Optical Readout Signal

Why Bother? - Cheaper and less time consuming than empirical methods

NA < 1

Use Scalar Diffraction Theory – i.e. light treated as a scalar

NA ≥ 1

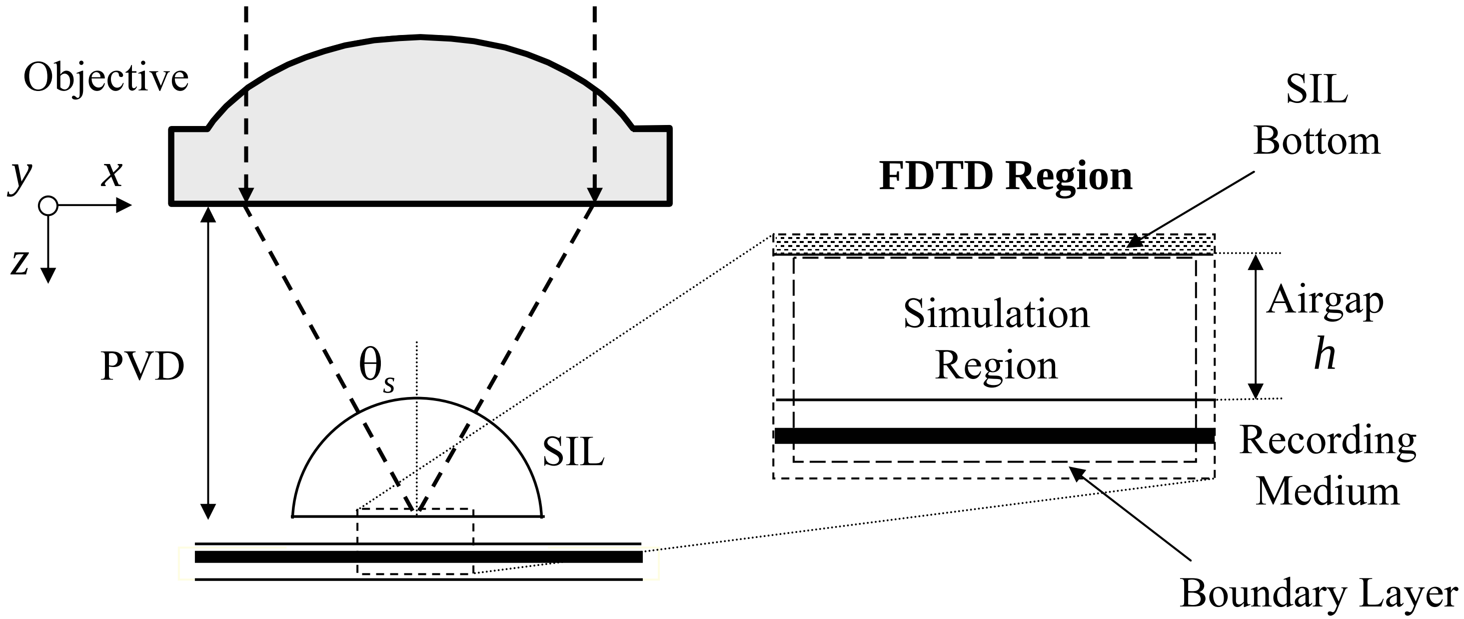
Complex light propagation -> more difficult problem

Researchers have used:

- Vector Diffraction Theory
- **Numerical Solutions of Maxwell's Equations**

Proposed Readout Signal Simulator

… composed of 3 main calculations:



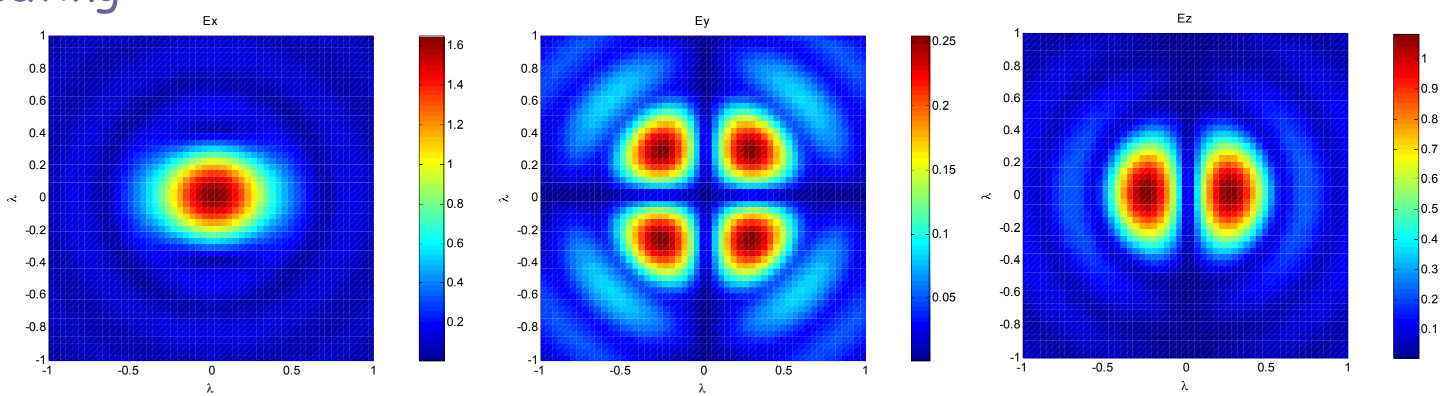
- 'Pseudo Vector Diffraction' (PVD) method calculates field distribution beneath SIL bottom (in absence of disc structure)
- Finite Difference Time Domain (FDTD) Region calculates interaction between incident beam & disc – SIL completely removed from sim. region
- Inverse PVD translates results back to objective aperture

(1) Incident Field Calculation

- PVD – scalar diffraction theory modified to account for the severe bending of rays upon propagation through a high-NA lens

- Simply stated, the field distribution at the focal point is calculated by FT of the aperture pupil function (field distribution at the exit pupil of the lens)
    - Accounts for any aberrations present e.g. defocus

- Not using full-vector -> less complicated computation & time-saving



- Results compare favourably with full-vector output at high NA_{eff}

(2) FDTD Simulation Region

•Uses FDTD to numerically solve scattered-field formulation time-domain Maxwell equations:

$$\bar{\epsilon}\frac{\partial E^{scat}}{\partial t} = -J - (\bar{\epsilon} - \epsilon_0)\frac{\partial E^{inc}}{\partial t} + (\nabla \times H^{scat})$$

$$\frac{\partial H^{scat}}{\partial t} = -\frac{1}{\mu_0}(\nabla \times E^{scat})$$

•FDTD approximates the partial derivates using:

$$\frac{\partial E^{scat}}{\partial t} = \frac{E^{scat,n} - E^{scat,n-1}}{\Delta t}$$

$$\frac{\partial H^{scat}}{\partial x} = \frac{H^{scat,n-\frac{1}{2}}(x_1, y, z) - H^{scat,n-\frac{1}{2}}(x_2, y, z)}{\Delta x}$$

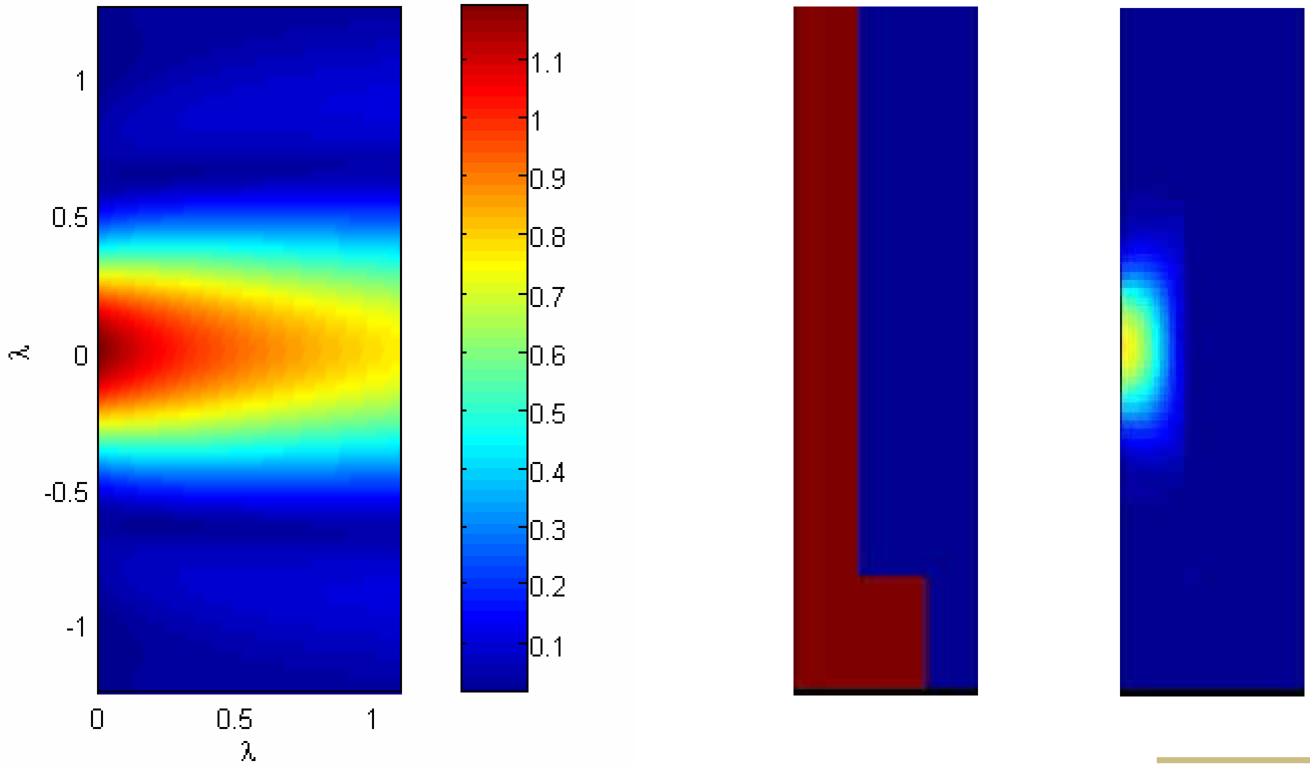
•Scattered-field formulation removes dispersion errors in incident field and reduces required size of FDTD region -> time saving

•Incident electric field: **E^{inc} = (PVD output)*$e^{j\omega t}$**

•PVD output only needs to be calculated once per simulation, not every time step -> significant time saving

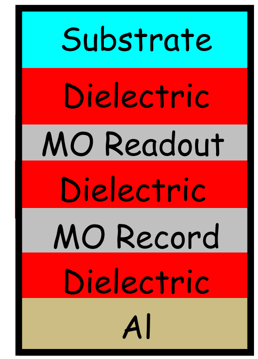
(2) FDTD Simulation

- Isolated Pit traversing SIL-focussed Beam
- NA = 0.85, n_{sil} = 1.8, Pit-depth = 0.25λ, Pit-length = 0.8λ



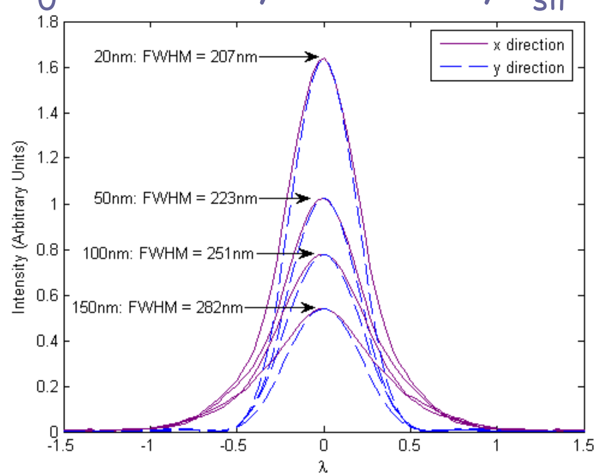
(2) FDTD Simulation

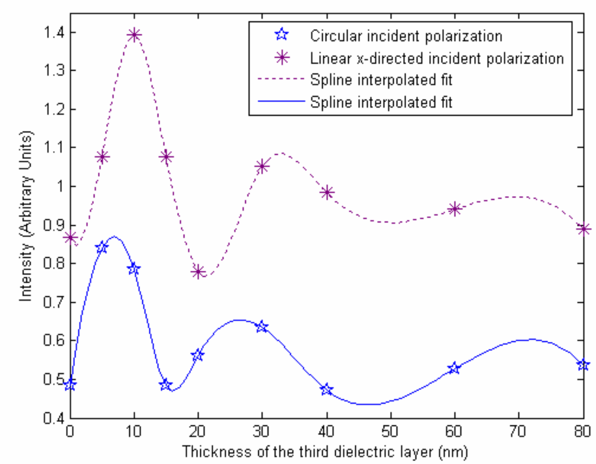
- System parameter optimisation capability



- Total-field beam-spot profile vs. airgap, Peak beam-spot intensity vs. Dielectric3 layer depth, measured at mid-plane of readout layer

- λ_0 = 405nm, NA = .85, n_{sil} = 1.8





- Airgap depth as small as possible, Dielectric3 depth optimum 10nm (linear x-polarisation) & ~7nm (circular polarisation)

(3) Readout Signal Estimation

- Inverse PVD translates FDTD output at the focal plane back to objective aperture

- For PC & ROM type discs we then integrate the inverse PVD output using

$$I = \int\int_{pupil} (|E_{xfar}(x_1, y_1)|^2 + |E_{yfar}(x_1, y_1)|^2) dx_1 dy_1$$

- For MO type disc such as MAMMOS we instead use

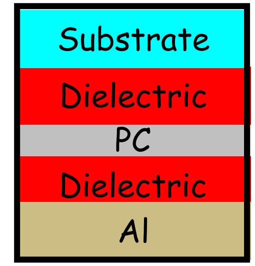
$$I = \int\int_{pupil} (0.5 * |E_{xfar}(x_1, y_1) + E_{yfar}(x_1, y_1)|^2 \\ -0.5 * |E_{xfar}(x_1, y_1) - E_{yfar}(x_1, y_1)|^2) \, dx_1 dy_1$$

Where I a readout signal at the current position of the disc

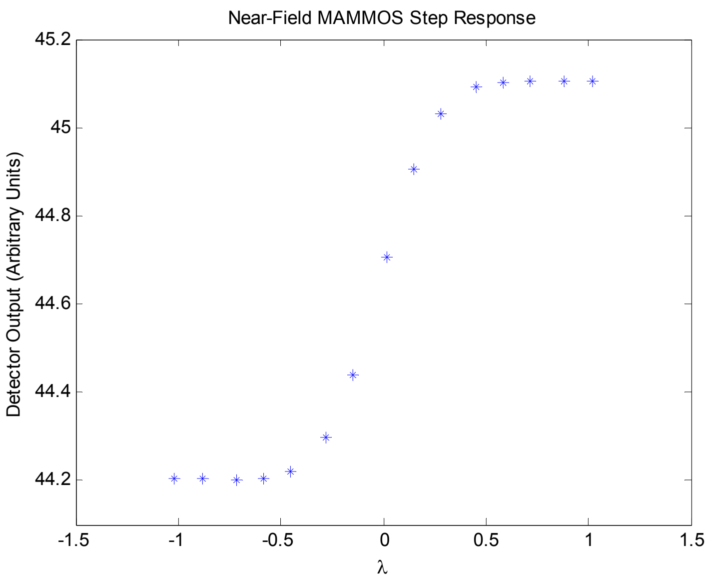
- Shift disc structure and repeat process

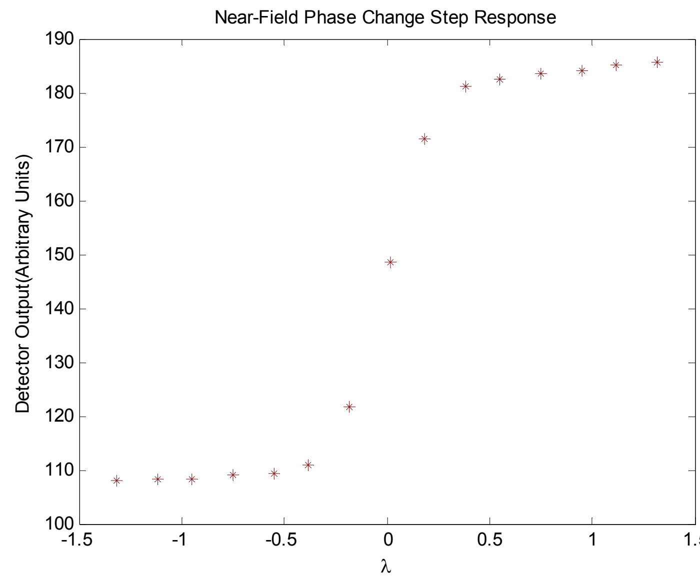
(3) Readout Examples

- Identical Simulation Parameters Used



- Readout Signals





- Significant Difference in ΔAmplitude
  - MAMMOS -> very small change

Conclusion

•Created rigorous simulator capable of fully analysing an optical storage system with arbitrary disc type and optional presence of a SIL

•Using the simulator, full-optimisation of near-field MAMMOS system is possible

•Reduced Calculation time due in comparison with alternative methods (Complete removal of SIL from FDTD space, use of PVD, use of scattered-field formulation)

To be published: 'FDTD Analysis of Recording Light Distribution in a Near-field MAMMOS Recording System,' IEEE Trans. Magn., October 2005.

Questions?