Using a multimodal waveguide for enhanced resolution in optical data storage

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Abstract **Optical data storage tries to cope with the strong need for exchangeable super high-density, high-data rate storage memories that can be easily copied and can be produced at low cost. In this search for higher information density, the classical diffraction limit forms an important barrier. In this paper we propose a method to improve the optical resolution without making the spot size on the disk smaller than the wavelength. The idea is to reconstruct the bit pattern from the complete field profile (including amplitude and phase) of the light response of reflected on the disk. Phase and amplitude information are measured by picking up the wave front into different modes of a multimodal waveguide. Once picked up, these modes can be split up by a photonic integrated circuit to be measured by different detectors.**

I. Introduction

A. *Optical data storage today: from CD to Blu-ray*

Since the first compact disk (CD) 20 years ago, optical data storage technology has undergone a rapid evolution. Being originally a read only medium, recordable and rewritable disk were developed. Not only an increase in storage density from 650 Mb (CD) to 25Gb (Blu-ray) has been made possible, but also the cost has dropped down and the data rate increased enormously.

In spite of this rapid evolution the main principle has however remained the same: The disk consists of tracks with bumps and holes. Using a lens system a tiny spot on this disk is illuminated. By capturing the reflection of this spot on a detector, the bit pattern can be registred electronically. The smaller the tiny illumination spot, the smaller the bumps and holes, the higher the information capacity. Unfortunately this ilumination spot can not be made infinitely small, because the laws of optics define a so called diffraction limit: the diameter of the spot is always larger than the wavelength. By using shorter wavelengths and better lenses, todays optical disk systems are very close to this limit.

B. *Phase information*

Light is complex, it has an amplitude and a phase component. When captured on a detector only the amplitude component is measured. By detecting phase as well as amplitude information a superior resolution can be achieved. In a noise free world it would even be possible to achieve infinite resolution by detecting the total (complex) field. But even with the existing noise it should be possible to enhance the conventional pick-up. Our approach for detecting this phase information is using a multimodal waveguide as pick-up head instead of a detector.

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II. Illumination and detection

A. *The scanning waveguide approach*

Fig.1 shows a schematic version of our scanning waveguide approach. Through the multimodal waveguide light is focused on the disk, using one of the modes of the waveguide or a linear combination of the modes. This light reflects on the disk and couples back into the different modes of the waveguide. To control those different modes in the waveguide we use a photonic IC, which excites and detects the different order modes in the multimodal waveguide from and to monomodal input and output waveguides. This way we can measure the reflection matrix formed by the mode to mode coupling from the waveguide to the disk and back. On Fig.1 is shown how light is picked up by scanning the waveguide over the disk with a smal air gap, but it is also possible to use a lens system without changing the results of our approach. are shown only the zeroth and the first order mode, but more modes can be used for illumination and detection.

B. *Simulation results*

On fig. 2a two bit patterns are shown as a change in reflectivity of the disk. The length of the bits is 0.2 λ. The bit patterns in black dashed line and in gray continuous line have only one bit in difference. On fig. 2b is shown how the mode-to-mode coupling is changing when the waveguide is moved along those two bit patterns. While there is no obvious connection between the bit patterns and the response curves, it must be clear that if the two different bit patterns generate response curves are significantly different the bit pattern can be deduced. The mode-to-mode coupling coefficients were calculated with the simulation tool CAMFR[1]. This program is rigorously vectorial but can only handle two-dimensional components. Therefor our simulations are based on two-dimensional models of waveguide and disk. The simulation results are independent of the wavelength, but to show a proof of principle a wavelength of 980 nm was used for the design of waveguide and photonic IC. The air gap in our simulations is one wavelength. At this distance most evanescent waves are already lost, but propagation has not yet fully shaped the distribution.

III. A PHOTONIC IC SPLITS UP THE MODES

To detect the evolution of the mode-to-mode coupling matrix a photonic IC is needed. It is hard to detect all elements of this matrix, but it may be sufficient only to detect some of them. As mentioned above a low crosstalk for the splitting of the different modes is very important. A component that splits off zeroth and first order mode has been designed and fabricated. The principle of the mode splitter is based on restricted interference in a multimode interferometer[2][3]. As is shown on fig. 3, the splitter replicates the zeroth order mode at the central output waveguide and splits the first order mode up into two zero order modes at the two outer output waveguides. The components were fabricated out of a GaAs/AlGaAs-wafer with an etch depth of 180nm. The components were measured extensively. Experimental crosstalk levels down to –20dB were detected. The component also proved to be relatively intolerant to small fabrication inaccuracies.

IV. CONCLUSION

The scanning waveguide approach can be a new method for read-out of optical disks. By detetcting as well phase as amplitude information it can achieve superior resolution. The diffraction limits still stands but our approach gives a much better contrast within this resolution. This enables us to detect smaller bitpatterns.

V. TABLES AND FIGURES

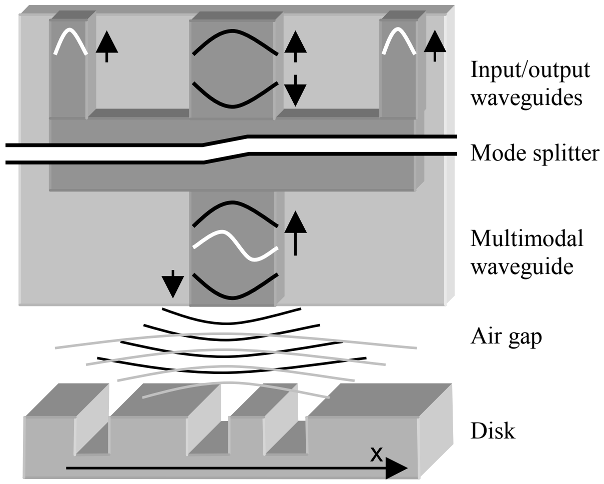

Figure 1: Shematic view of the PIC, waveguide and disk.

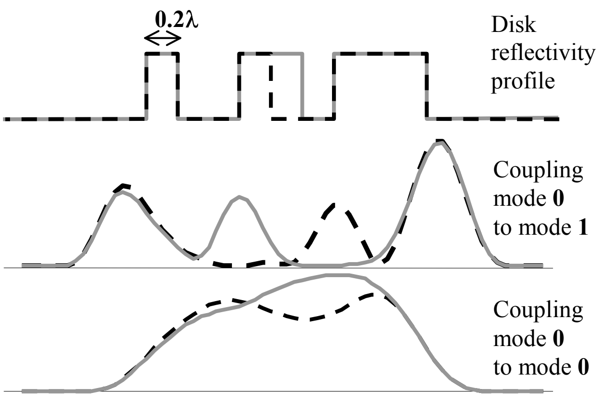

Figure 2a: Two bit pattern with bit length 0.2 λ
Figure 2b: Mode-to-mode coupling coefficients when scanning along the bit pattern

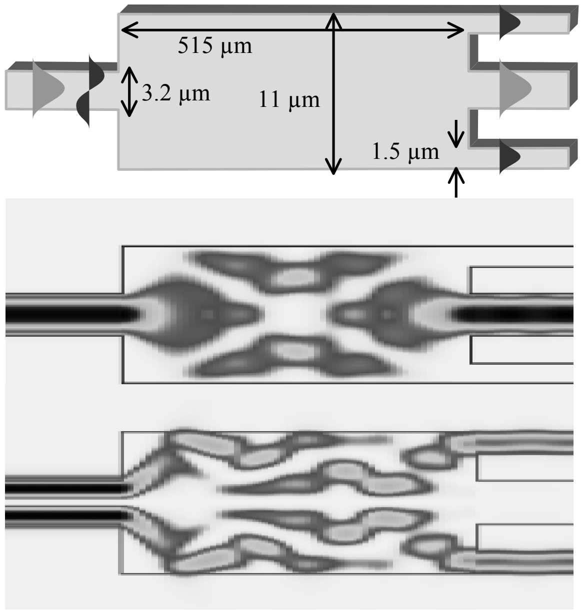

Figure 3a: Mode splitter dimensions
Figure 3b: Optical fields inside the splitter for mode 0 and mode 1

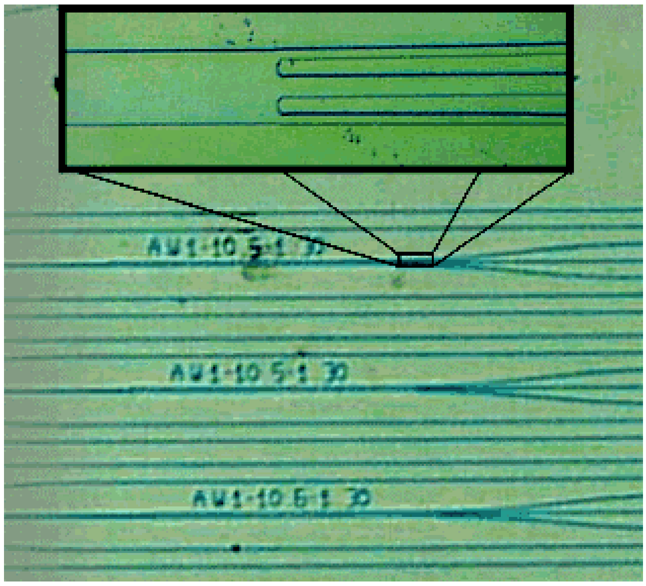

Figure 4: Detail of the fabricated components

ACKNOWLEDGEMENTS

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REFERENCES

[1] http://camfr.sourceforge.net.
[2] L.B. Soldano, E.C.M. Pennings, "Optical multi-mode interference devices based on self-imaging: principles and applications", IEEE Journal of Lightwave Technology, vol. 13, pp. 615-627, April 1995.
[3] J. Leuthold, R. Hess, J. Eckner, P.A. Besse and H. Melchior, "Spatial mode filters realized with multimode interference couplers", Optics Letters, vol. 21, pp. 836-838, 1996.